

Tracking the Sun

Pricing and Design Trends for Distributed Photovoltaic
Systems in the United States

2022 Edition

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Overview

Summarizes installed prices and other characteristics of grid-connected, distributed solar photovoltaic (PV) systems in the United States

- Current edition focuses on projects installed through 2021
- Covers both stand-alone PV and paired PV+storage
- Describes trends related to:
 - **Project characteristics**, including system size and design, ownership, customer segmentation, and other attributes
 - **Median installed price trends**, both nationally and by state, including preliminary data for first half of 2022
 - **Variability in pricing** according to system size, state, installer, equipment type, and other factors, relying on both descriptive and econometric analysis

Accompanying Data Products
available at trackingthesun.lbl.gov

1. **Summary brief:** A short narrative summary of the full slide-deck report
2. **Data visualization tool:** Allows users to create custom figures and explore the full *Tracking the Sun* dataset
3. **Public data file:** The underlying project-level dataset, excluding confidential data
4. **Summary tables:** All figures and underlying summary tables are available in a MS Excel workbook

Report Structure

- [Data Sources, Methods, and Market Coverage](#)
- [PV System Characteristics](#)
- [Paired PV+Storage System Characteristics](#)
- [Median Installed Price Trends](#)
- [Variability in Installed Prices](#)
- [Multi-Variate Regression Analysis of Residential Installed Prices](#)
- [Appendix](#)

Data Sources, Methods, and Market Coverage

Data Sources

***Tracking the Sun* relies on project-level data**

- Provided by state agencies, utilities, and other organizations, for PV systems participating in incentive programs, renewable energy credit registration systems, and interconnection processes
- Some of these data already exist in the public domain (e.g., California's Currently Interconnected Dataset), though LBNL may receive additional data under non-disclosure agreements
- Supplementary data from building permit records for Hawaii provided by Ohm Analytics (used in storage-related material)

66 entities spanning 30 states contributed data to this year's report (see Appendix)

- Some of these are legacy data sources that no longer contribute incremental data each year; incremental data for 2021 come from 41 organizations in 25 states

Key Definitions and Conventions

Customer Segments

- **Residential:** Single-family and, depending on the data provider, may also include multi-family
- **Small Non-Residential:** Non-residential systems $\leq 100 \text{ kW}_{\text{DC}}$
- **Large Non-Residential:** Non-residential systems $> 100 \text{ kW}_{\text{DC}}$ (and $\leq 5,000 \text{ kW}_{\text{AC}}$ if ground-mounted)
 - * *Independent of whether connected to the customer- or utility-side of the meter*

Units

- Real 2021 dollars (unless otherwise noted)
- Direct-current Watts (W_{DC}), unless otherwise noted

Installed Price: Up-front price ($2021\$/\text{W}_{\text{DC}}$) paid by the PV system owner

- Prior to incentives (i.e., the gross price)
- Inclusive of any up-front loan-financing fees passed through the installer

Sample Frames and Data Cleaning

Full Sample

Used to describe system characteristics
The basis for the public dataset

1. Remove systems with missing size or install date
2. Standardize installer, module, inverter names
3. Integrate equipment spec sheet data
 - Module efficiency and technology type
 - Inverter power rating
 - Flag microinverters or DC optimizers
4. Convert dollar and kW values to appropriate units, and compute other derived fields

Installed-Price Sample

Used in analysis of installed prices

5. Remove systems if:
 - Missing installed price data
 - Third-party owned (TPO)*
 - Battery storage co-installed
 - Self-installed

Separate side analyses performed comparing:

- *TPO vs. host-owned*
- *paired PV+storage vs. stand-alone PV*

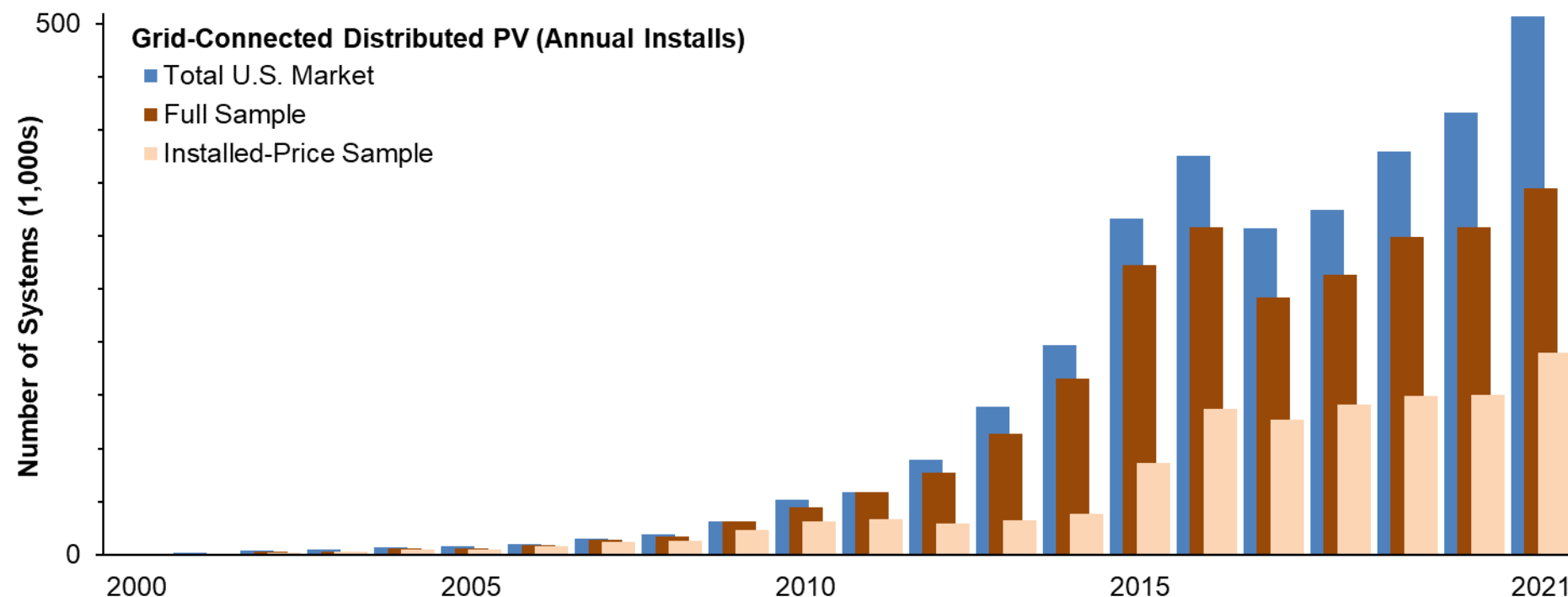
Sample Size Relative to Total U.S. Market

Full Sample

- 2.5 million systems through 2021 (77% of U.S. market)
- 340,000 systems installed in 2021 (68% of U.S. market)

Installed-Price Sample

- 1.2 million systems through 2021
- 190,000 systems installed in 2021



Gap between Full Sample and Total U.S. Market: Associated mostly with smaller and mid-sized state markets either missing or under-represented in the sample; see next slide

Gap between Installed-Price Sample and Full Sample: Primarily TPO systems and systems missing installed price data; several states included in the full sample provided no installed price data

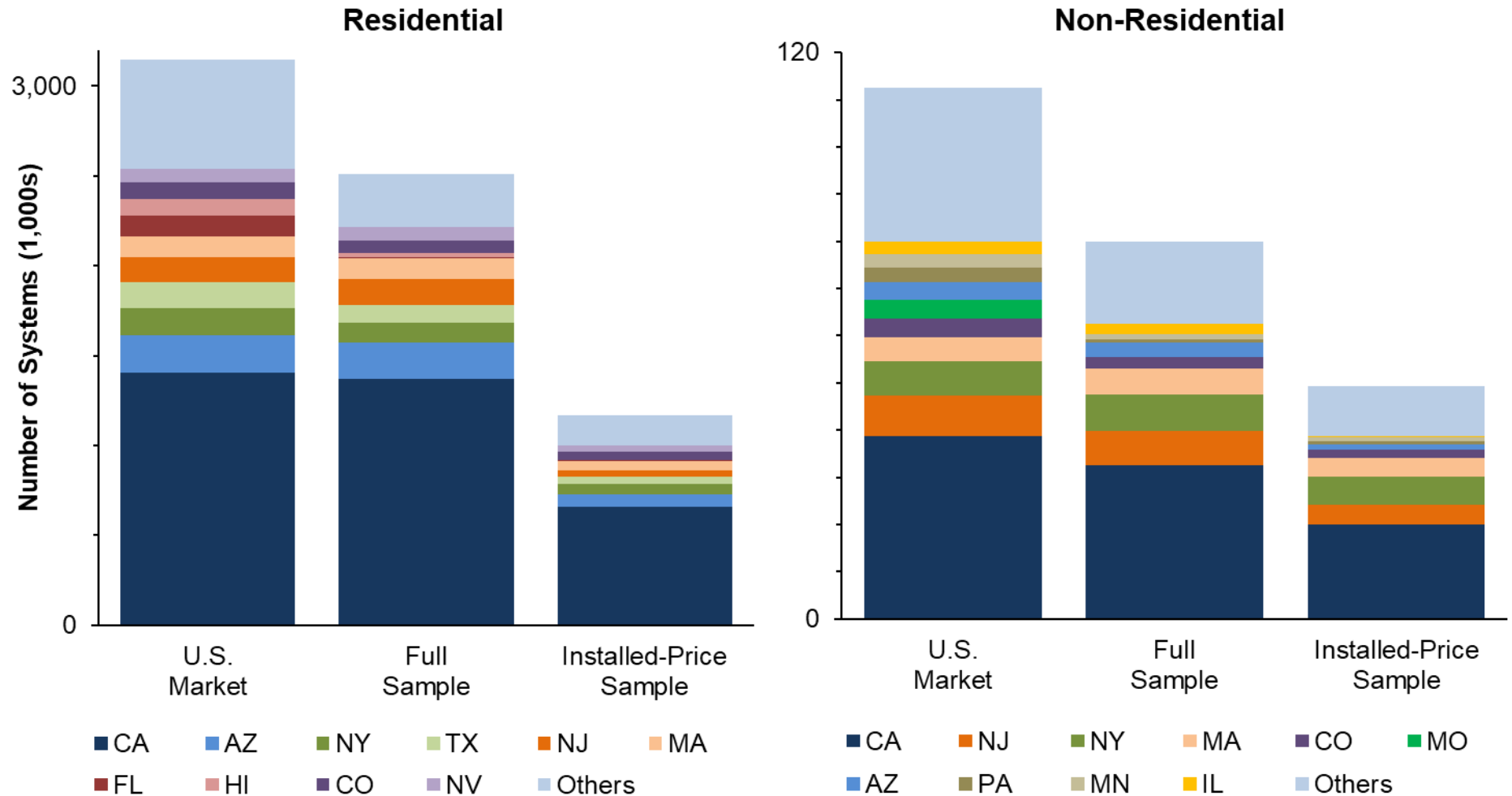
State-Level Sample Distribution and Market Coverage

Sample Distribution: CA dominates the sample, as in the larger U.S. market

Market coverage:

- Similar overall level of market coverage for both residential and non-residential
- In general, coverage among the larger state markets is fairly strong, the main exception being FL
- The bigger gap in the sample is for the collection of smaller state markets (aggregated in the figures as “Others”)

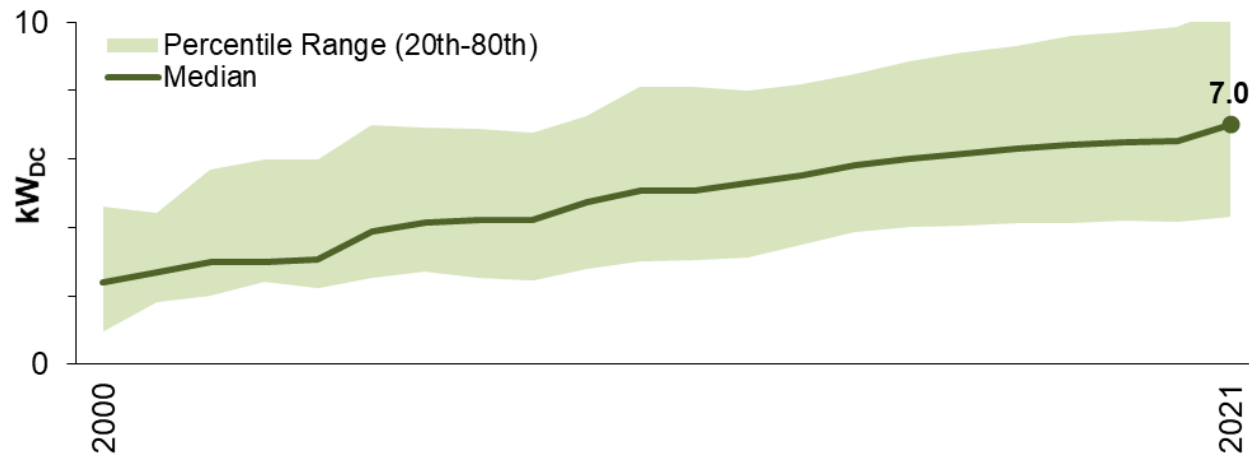
Cumulative Installs through 2021 (thousands)



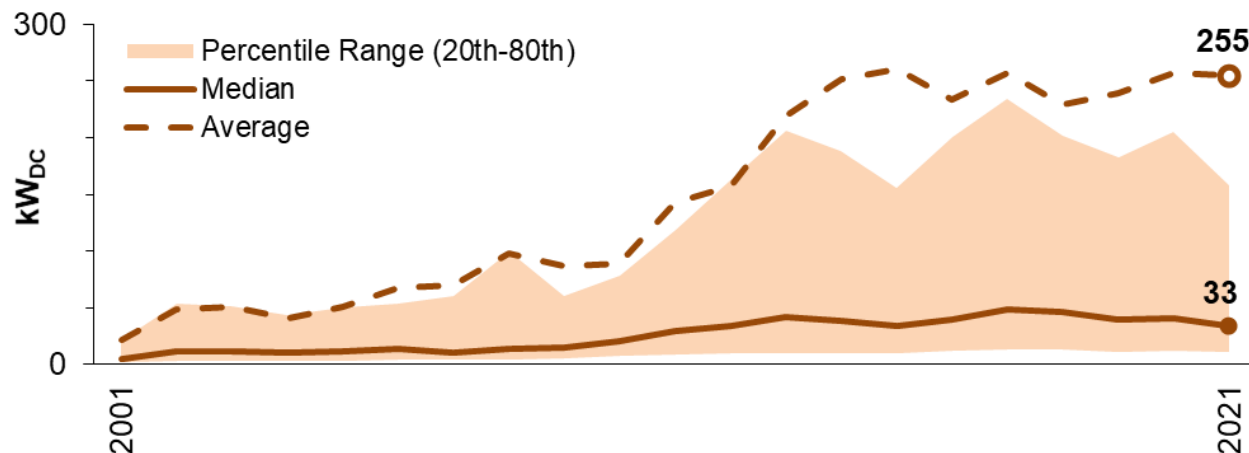
PV System Characteristics

System Size Trends

Residential System Size Time Trends



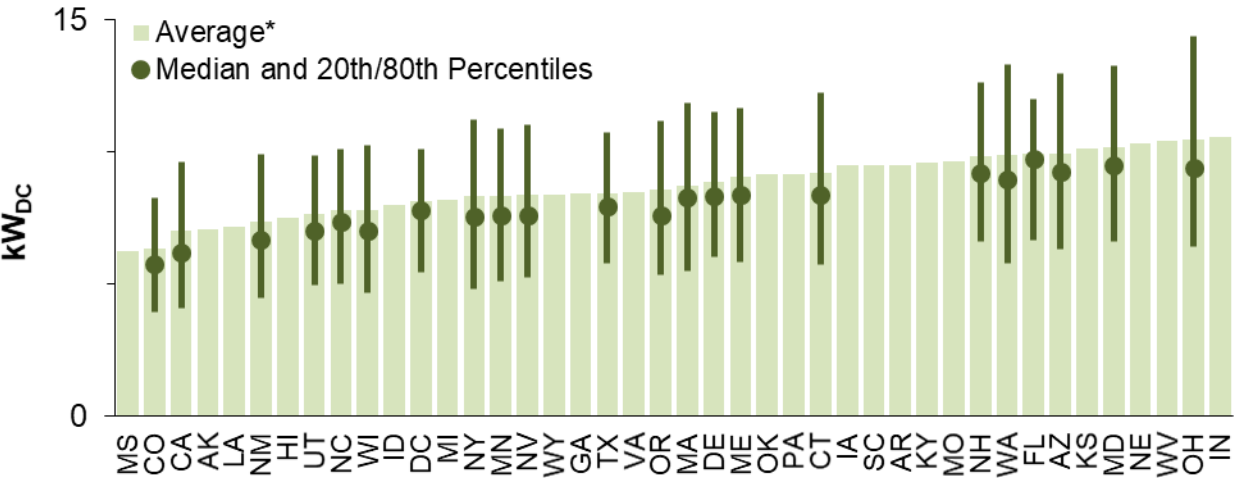
Non-Residential System Size Trends



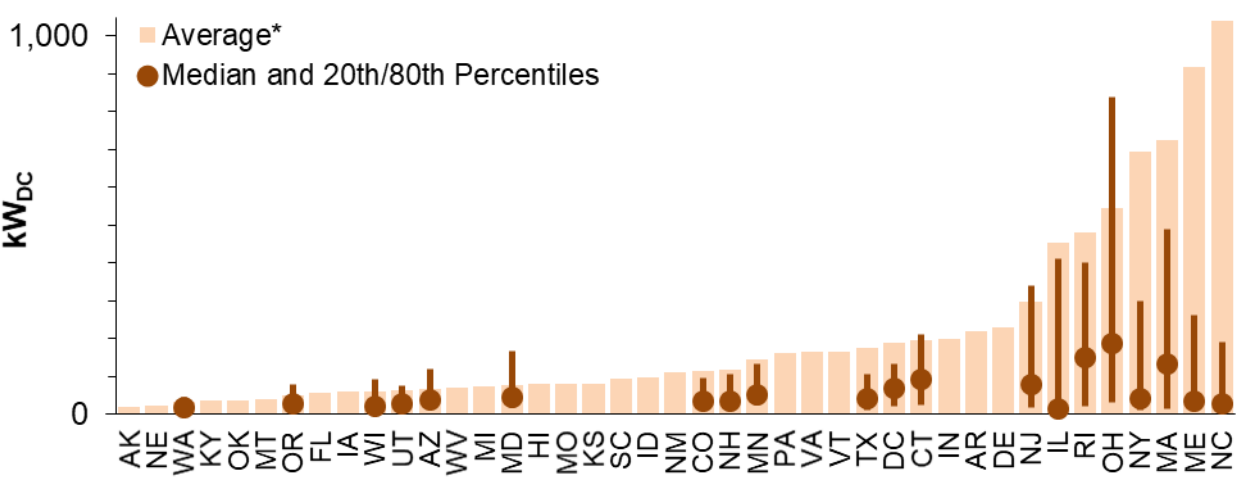
- Residential system sizes have been rising steadily over the past two decades, driven by declining costs and rising module efficiencies, among other factors
- Median residential system sizes reached 7.0 kW in 2021, with most systems ranging from 4-10 kW in size (the 20th to 80th percentile band)
- Non-residential sizes have also risen over time, especially at the upper end of the size range, though trends have flattened over the past decade
- While the median non-residential system size was just 33 kW in 2021, the distribution has a long upper tail, with 20% of systems in 2021 larger than 150 kW, and an average size of 255 kW
- Later trends distinguish small vs. large non-residential

System Size Comparisons by State

Residential System Sizes by State (2021)



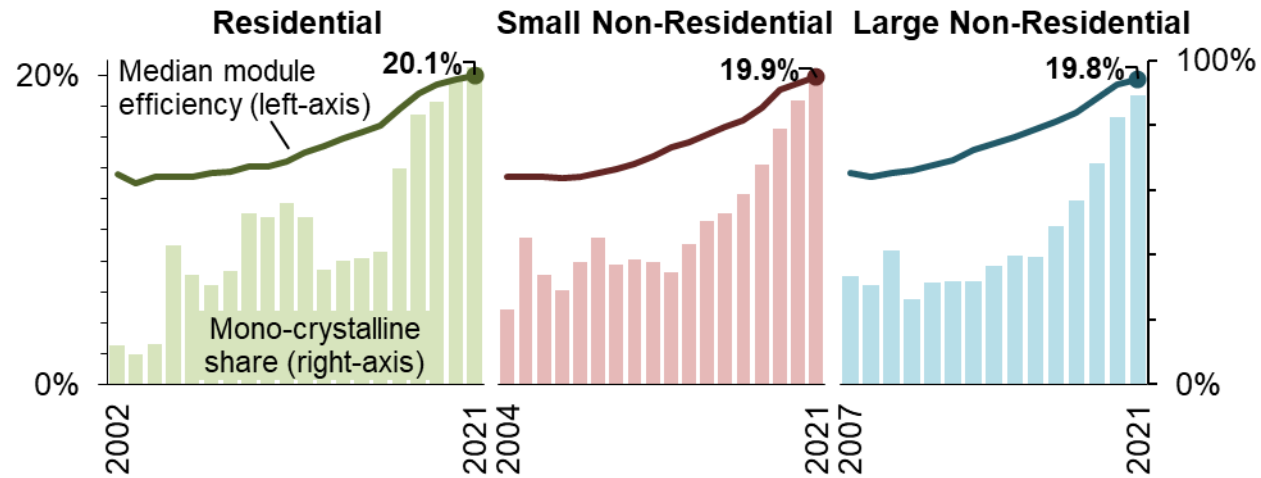
Non-Residential System Sizes by State (2021)



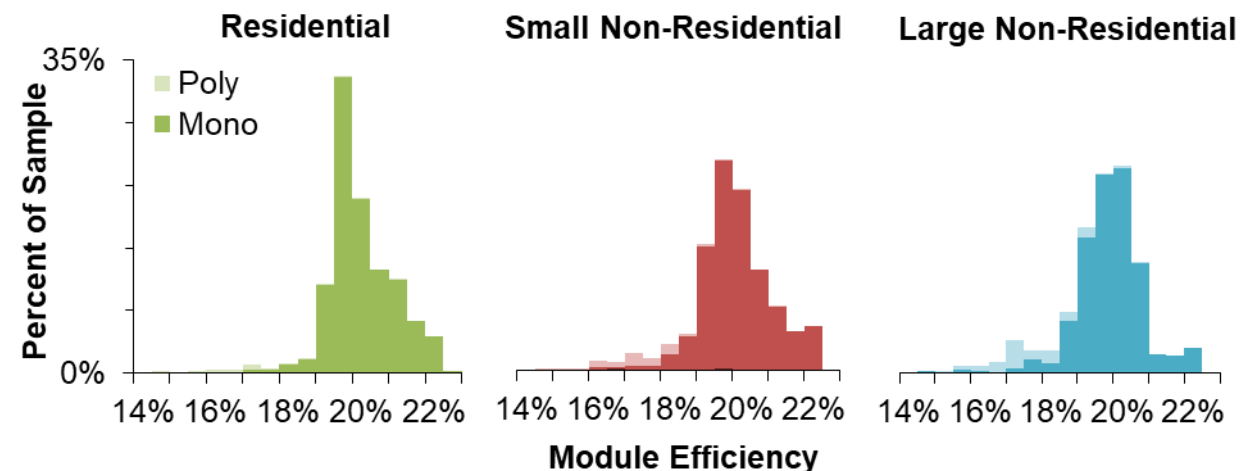
- Residential system sizes vary across states, reflecting regional factors such as typical consumption and insolation levels, among other factors
 - Median system sizes range from 6-10 kW, with a similar spread in average prices
 - System sizes also vary across projects within each state, reflecting customer-specific conditions
- State-level differences in non-residential system sizing are most notable at the upper tail of the distributions, which drives large differences in average sizes
 - States on the right-hand side all had a relatively significant share of large systems (keeping in mind how the non-residential sector is defined in this report)
 - In most states, the vast majority of non-residential systems installed in 2021 were <100 kW

Module Efficiency Trends

Module Efficiency Time Trends



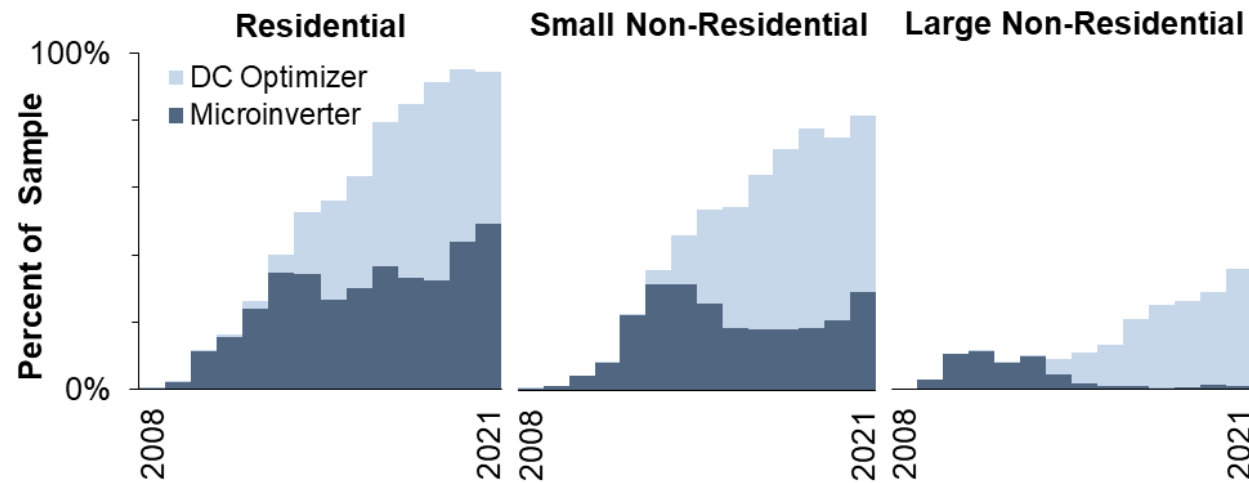
Module Efficiency Distribution (2021)



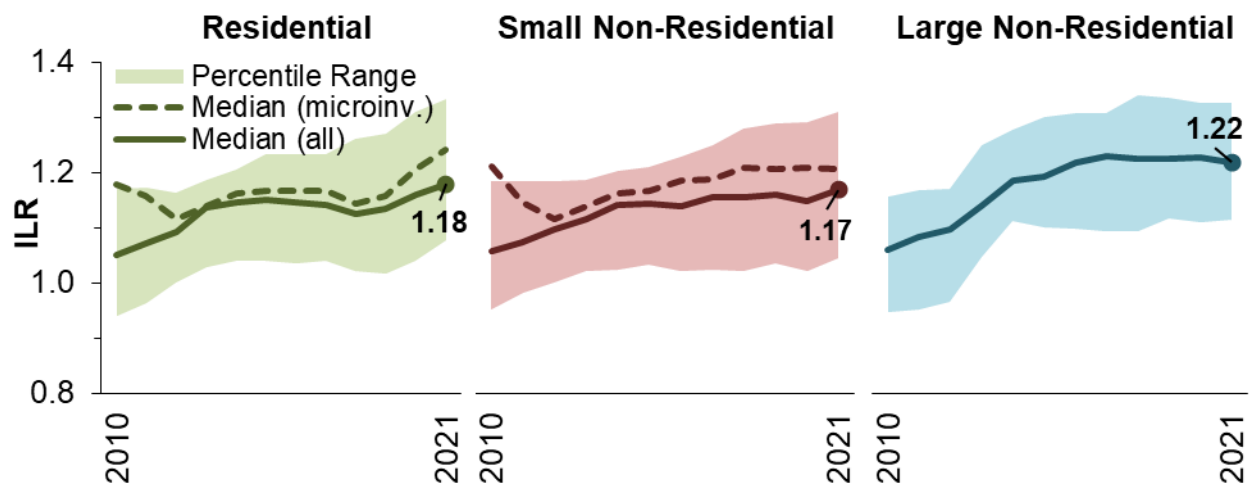
- Module efficiencies have risen steadily over time: for example, among residential systems, median module efficiencies rose from 13.6% in 2002 to 20.1% in 2021, with similar rises for non-residential systems as well
- Rise in recent years partly reflects rapid increase in market share of mono-crystalline modules (89-98% share in 2021, depending on the segment), as well as other factors—e.g., increasing use of passivated emitter rear-cell (PERC) technology
- Across systems installed in 2021, the vast majority had module efficiencies ranging from 19-21%; below that range are mostly poly-silicon modules, and above that range are premium-efficiency modules offered by a handful of manufacturers

Inverter-Related Trends

Microinverter and DC Optimizer Trends



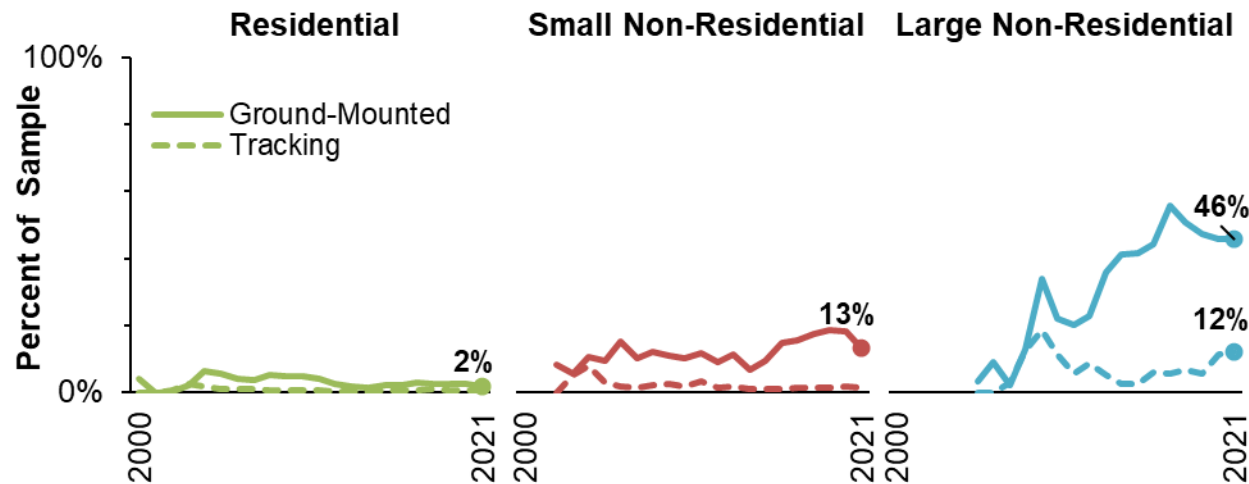
Inverter Loading Ratios (DC-to-AC Ratio)



- Module-level power electronics (MLPEs), which include both microinverters and DC optimizers, have continued to gain share across the sample
- MLPEs are almost universal within the residential sector (94% of systems in 2021) and dominant for small non-residential (81%), but considerably less common for large non-residential (36%) albeit growing steadily
- DC optimizers dominate MLPE growth since 2013, but microinverter share has been on the rise in recent years
- Inverter-loading ratios (the ratio of module-to-inverter nameplate ratings) have generally grown over time with declining module costs; also tend to be higher for large non-residential systems and for systems with microinverters (depending on manufacturer)

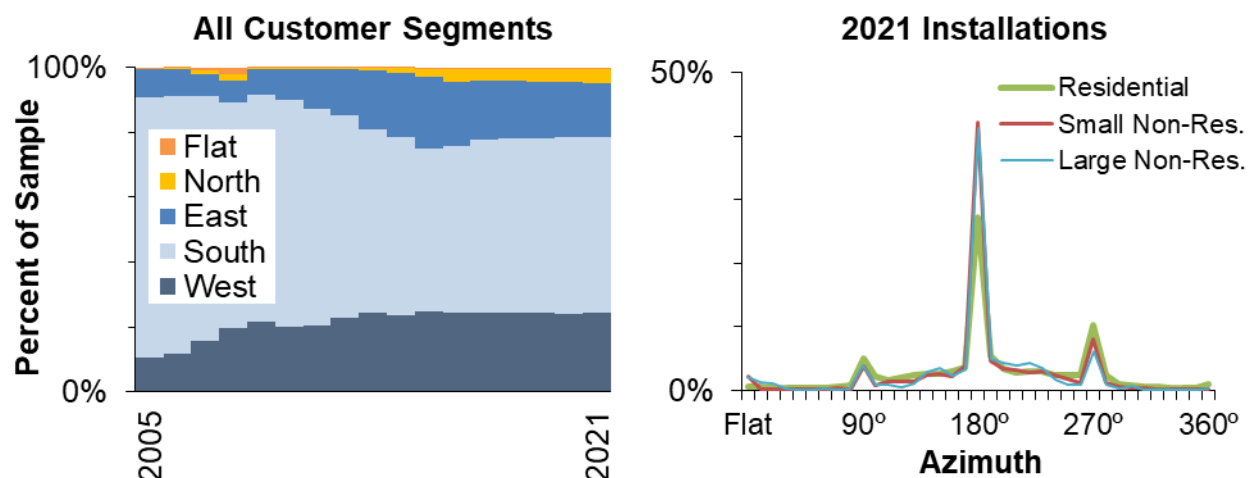
Mounting Configuration and Panel Orientation

Ground-Mounting and Tracking Equipment (2020)



- Ground-mounting (as opposed to roof-mounting) is most prevalent among large non-residential systems, while use of tracking is limited
 - Almost half (46%) of large non-residential systems in 2021 are ground-mounted, while 12% have tracking
 - Ground-mounting much less common among residential and small non-residential systems, and negligible shares have tracking

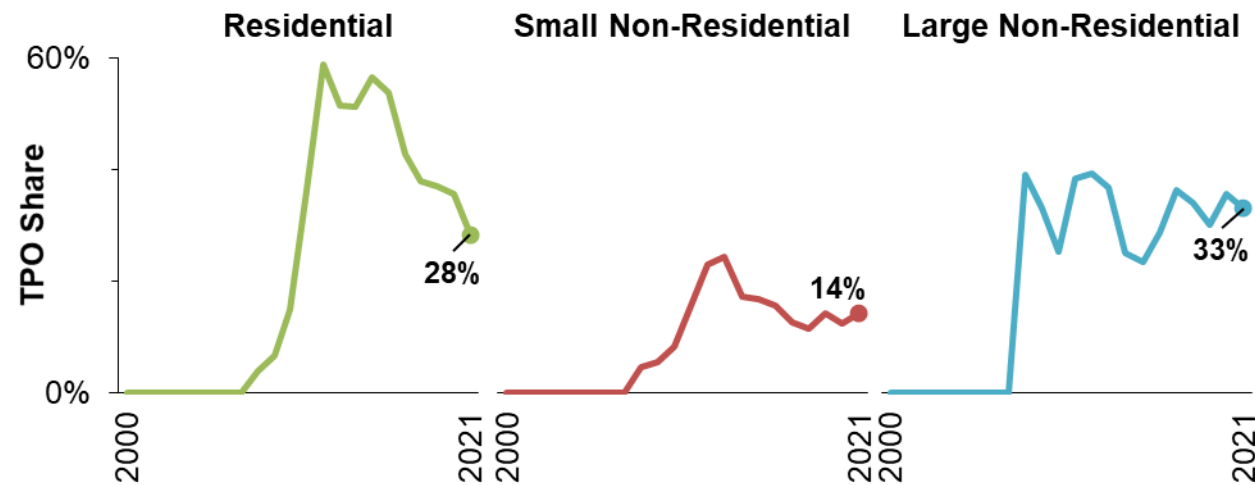
Panel Orientation



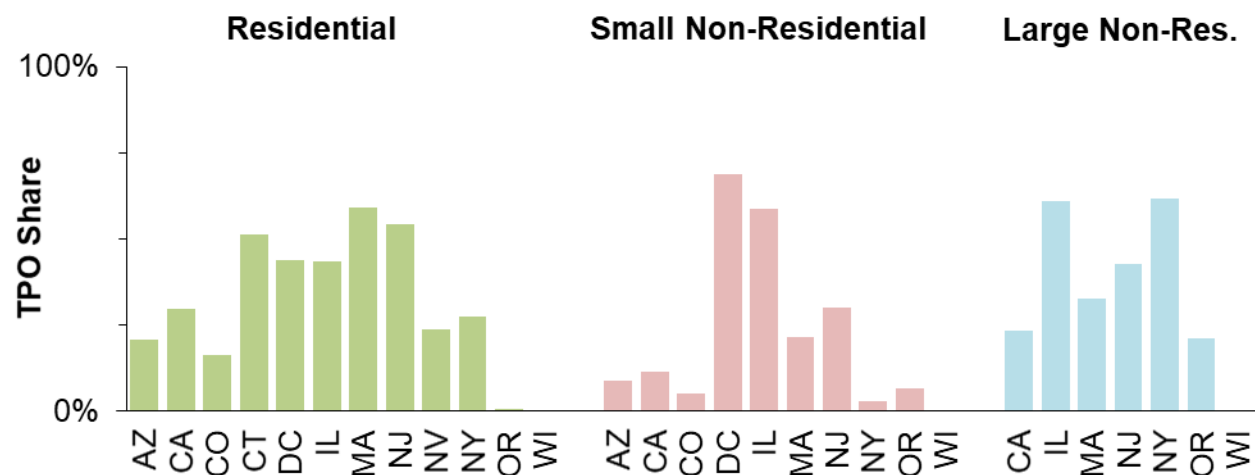
- Panel orientations have become more diverse over time, though haven't changed much in recent years
 - 54% of systems installed in 2021 face south, 24% to the west, and most of the remainder to the east
 - Greater share of non-residential systems faces exactly due-south, likely due to greater prevalence of ground-mounting and flat rooftops than in residential sector

Third-Party Ownership Trends

Third-Party Ownership Trends



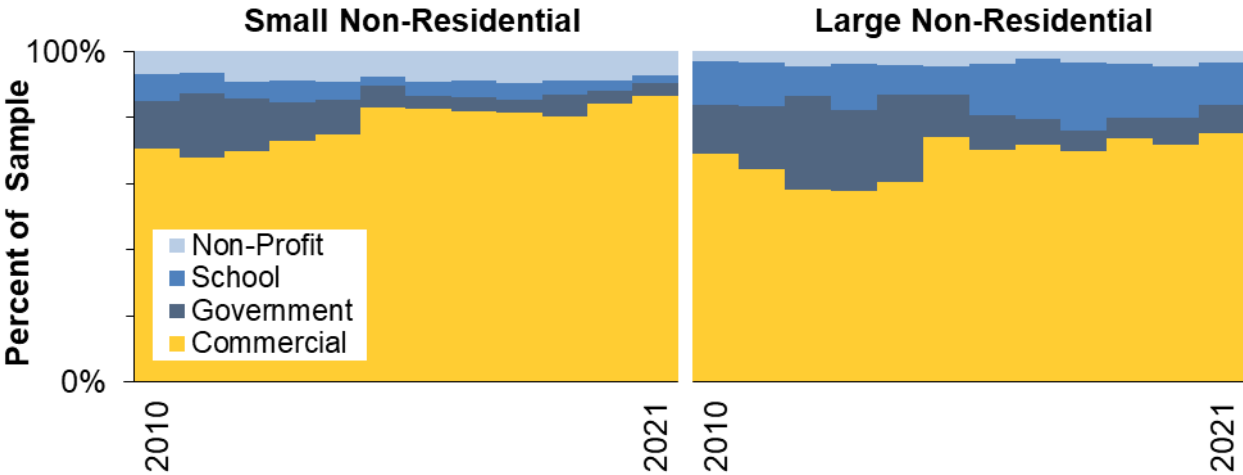
Third-Party Ownership by State (2021)



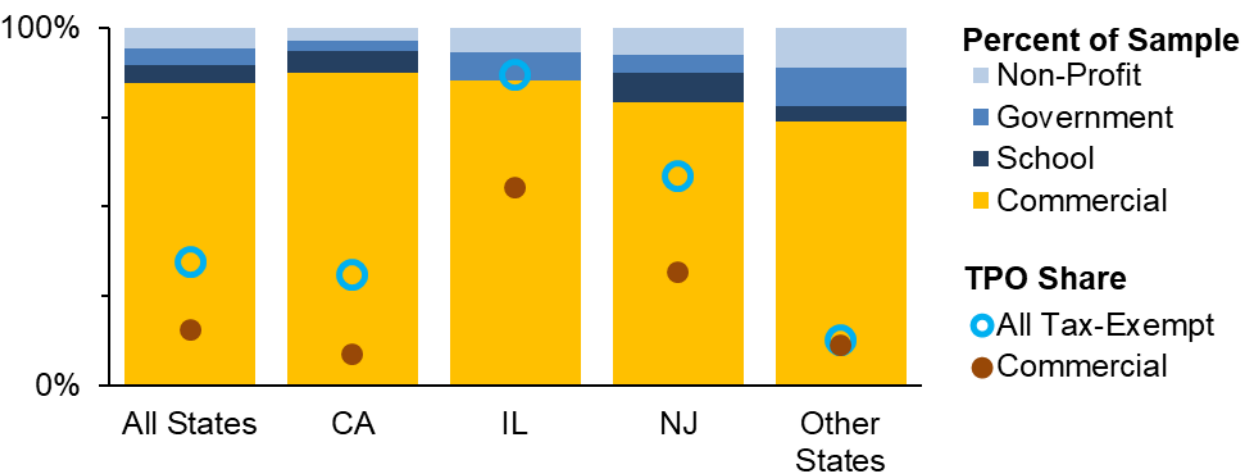
- Third-party ownership (TPO) in the residential sample has declined over time from its historical high of 59% in 2012 to 28% in 2021
 - Reflects emergence of residential loan products
- For the non-residential sample, TPO shares have remained comparatively steady and have historically been lower for small vs. large non-residential systems
- TPO shares at the state level vary substantially
 - Generally are higher among states with sizeable rebate programs (CT, IL) or high solar renewable energy certificate prices (DC, MA, NJ)
 - Some states limit TPO or restrict eligibility for incentive programs to only host-owned systems

Non-Residential Customer Segmentation

Non-Res. Customer Segmentation Trends over Time



Non-Res. Customer Segmentation by State (2021)



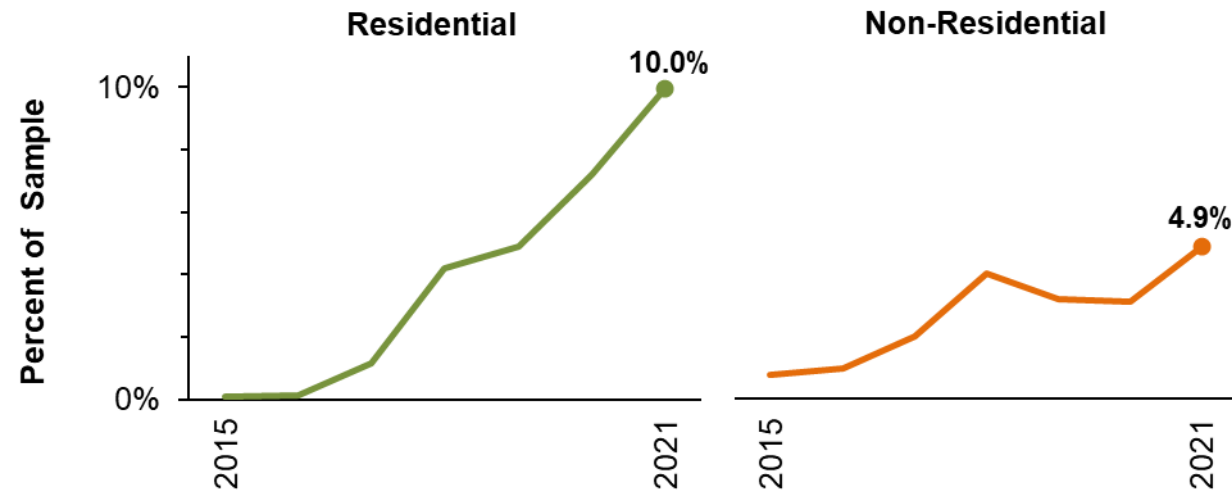
- For-profit commercial customers make up >75% of non-residential site hosts, with the remainder consisting of some combination of tax-exempt site hosts (schools, government, non-profits)
- Non-profits have been most prevalent among small non-residential systems, while schools and government facilities are more common within the large non-residential segment
- The overall mix of non-residential customer segments generally similar across states
- TPO generally more prevalent among tax-exempt site hosts than for commercial hosts (35% vs. 16% in 2021), as TPO allows tax-exempt customers to monetize tax benefits

Paired PV+Storage System Characteristics

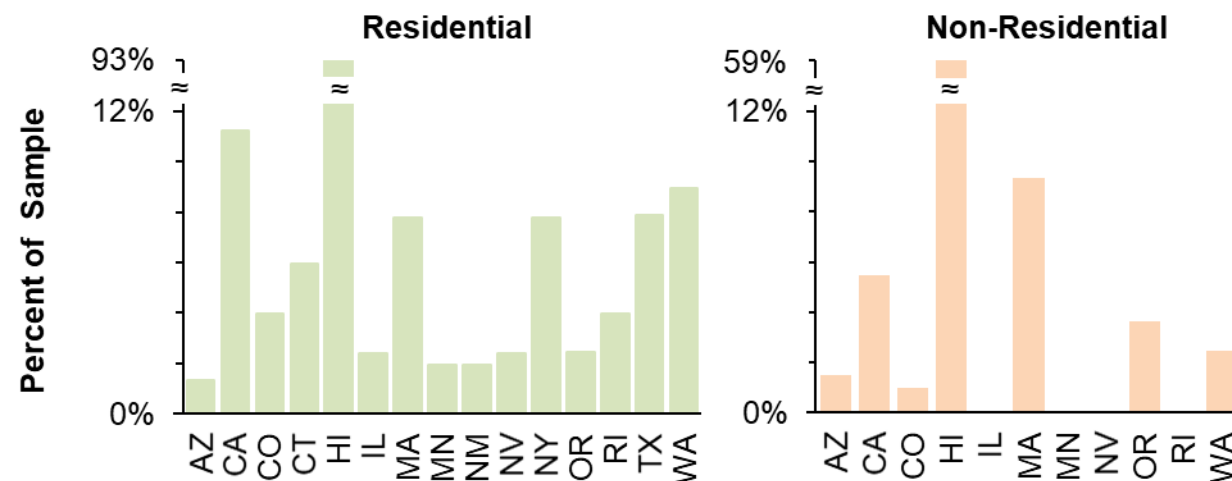
Storage Attachment Rates

Percent of PV systems installed each year with storage

Storage Attachment Rates over Time



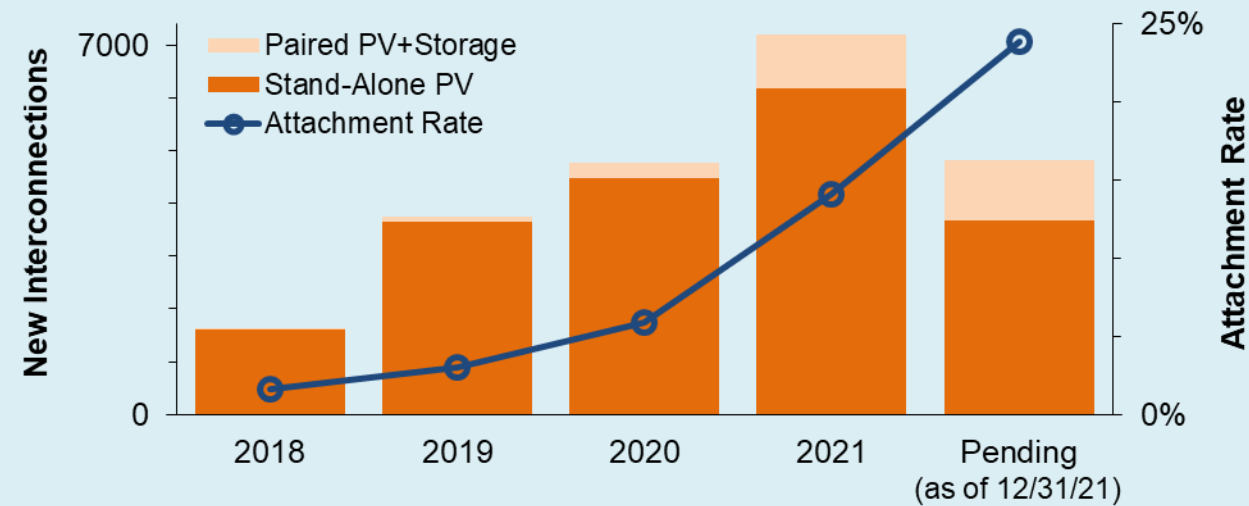
Storage Attachment Rates by State (2021)



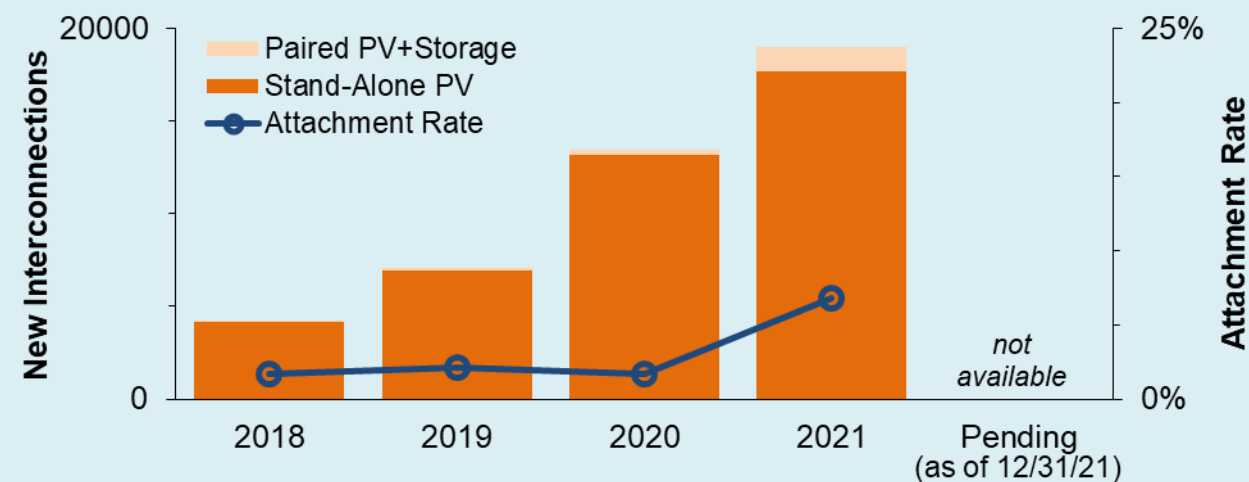
- Residential attachment rates have steadily risen over time, reaching 10% of the sample in 2021
- Non-residential attachment rates have fluctuated over time, but rose to an historical high of ~5% in 2021
- HI has, by far, the highest attachment rates of any state (93% residential, 59% non-res.), driven partly by net metering reforms that incentivize self-consumption
- CA, which hosts the vast majority of paired systems, has attachment rates of 11% (res.) and 5% (non-res.), driven by storage rebates and resilience concerns
- Other pockets of activity exist in the residential market (e.g., MA, NY, TX, WA)
- MA also stands out in the non-residential sector (9%), driven by SMART incentives

PV+Storage Growth in Texas after 2021 Winter Storm

CenterPoint (serving Houston metro area)



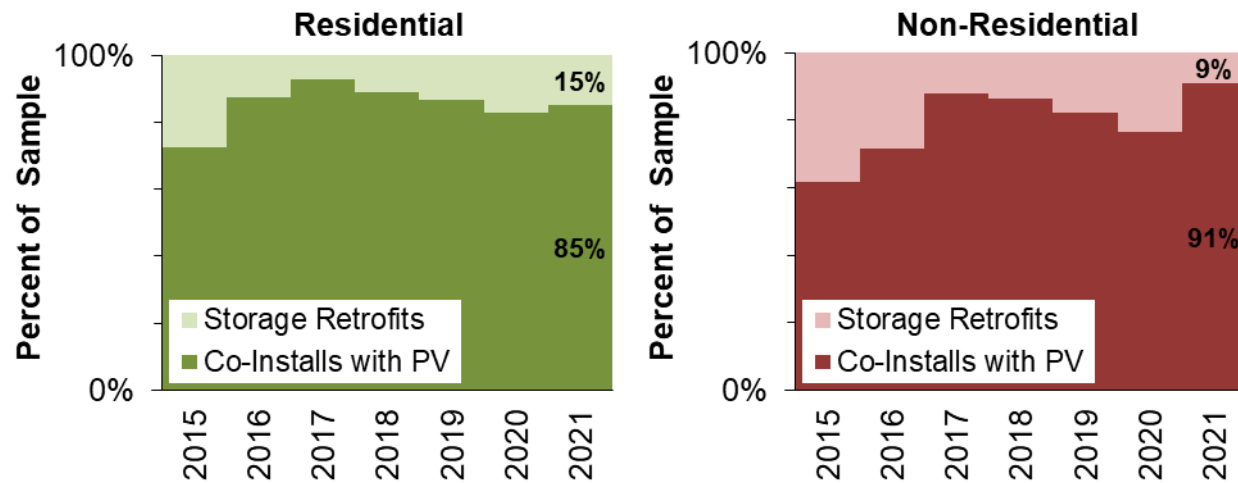
Oncor (serving Dallas/Fort Worth metro area)



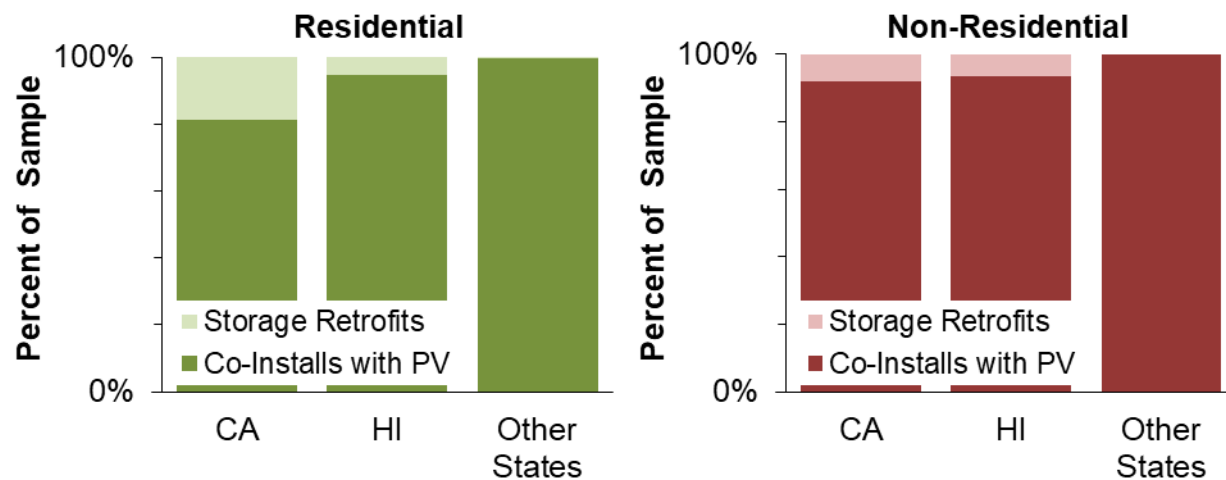
- An uptick in PV+storage adoption occurred after Winter Storm Uri, which hit Texas in February 2021
- From 2020-2021, new PV+storage interconnections increased by more than 3x in CenterPoint's service territory (from roughly 300 to 1,000) and by roughly 6x in Oncor's service territory (from 200 to 1,300)
- The uptick in attachment rates was most pronounced for CenterPoint, rising to 14% in 2021, and to 24% among applications pending at the end of the year
- Retail service providers in Texas also typically credit PV grid exports at less than the full retail rate, incentivizing PV customers to co-install storage in order to maximize self-consumption

Storage Retrofits to Existing PV Systems

Retrofits vs. Co-Installs by Year



Retrofits vs. Co-Installs by State (2021 Installs)

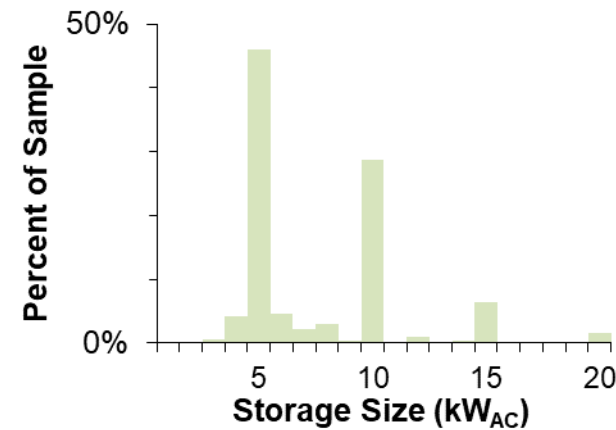


- Some storage systems paired with PV are installed as retrofits onto existing PV systems, rather than co-installed at the same time
- In both the residential and non-residential sectors, roughly 10-20% of all paired storage systems installed each year are retrofits (in 2021, 15% of residential systems and 9% of non-residential systems)
- Within the residential market, retrofits are considerably more common in California than in other states, likely driven the combination of wildfire-related resilience concerns and new time-of-use (TOU) rates with high peak-to-off-peak price differentials

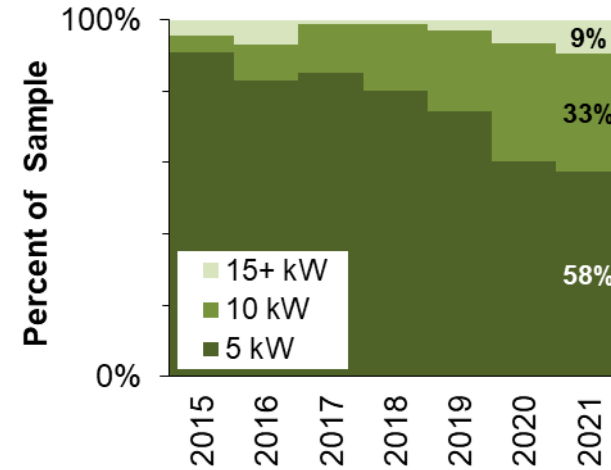
Residential Paired System Sizing

Storage Size Distribution

Systems Installed in 2021

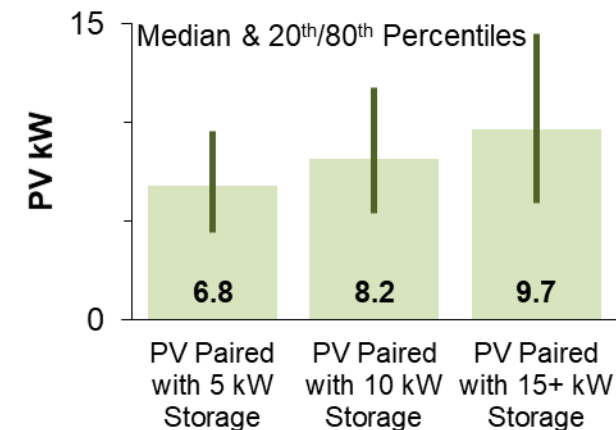


Storage Size Trend



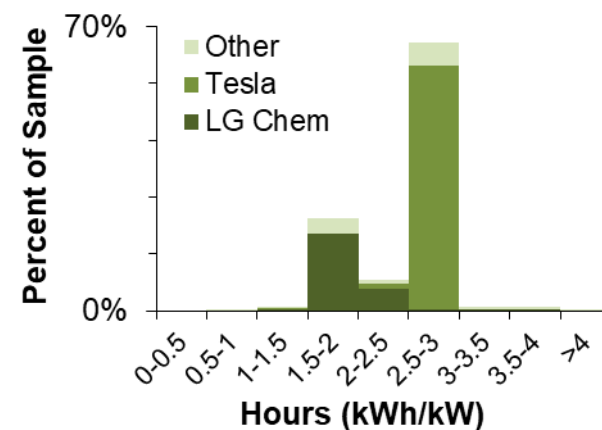
PV Sizing with Storage

Systems Installed in 2021



Storage Duration

Systems Installed in 2021

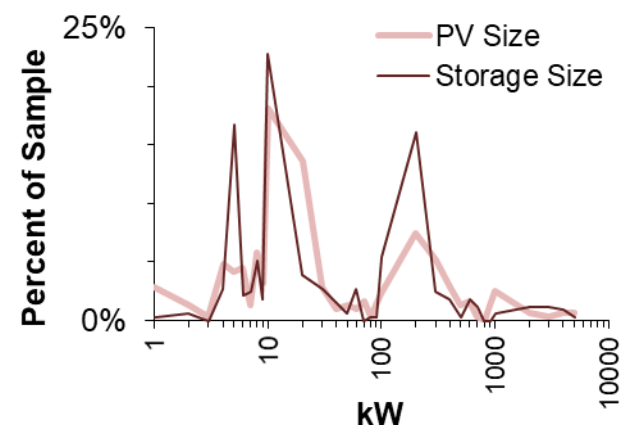


- Most residential storage systems paired with PV come in increments of 5 kW-storage
- The market has been trending toward systems with larger batteries, presumably driven in part by backup power demand → 42% of paired systems installed in 2021 had 10 kW or more of storage
- Paired systems with larger amounts of storage also tend to have more PV capacity
- Virtually all systems installed in 2021 had storage durations ranging from 1.5-3 hours (rated kWh/kW); reflects the two products that dominated market share (the LG Chem RESU10H @ 1.9 hrs and the Tesla PowerWall @ 2.7 hrs)

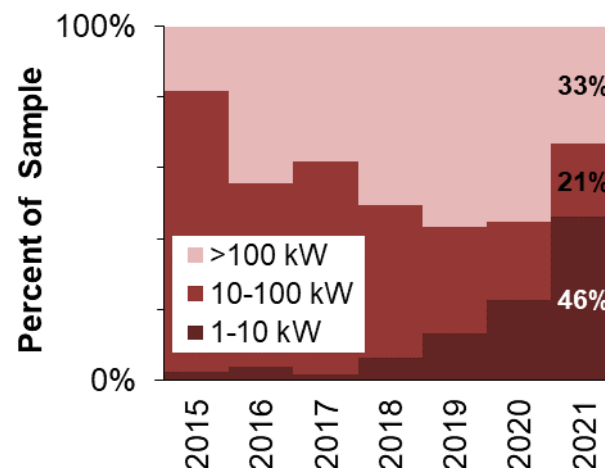
Non-Residential Paired System Sizing

Size Distributions

Systems Installed in 2021

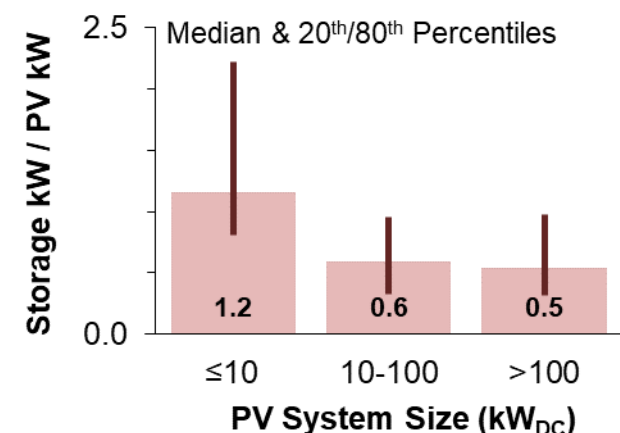


Storage Size Trends



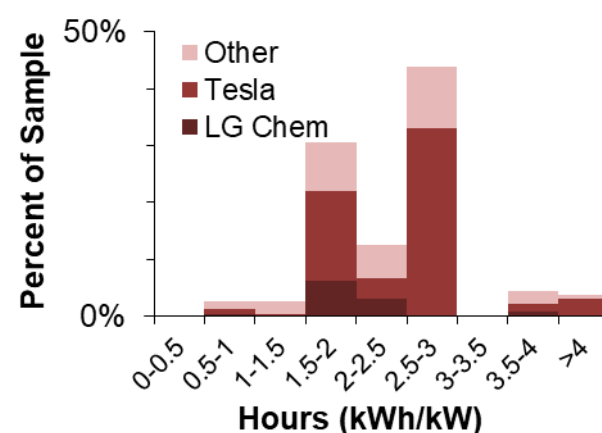
kW Ratio: Storage to PV

Systems Installed in 2021



Storage Duration

Systems Installed in 2021



- Most paired non-residential systems installed in 2021 were relatively small, with PV and storage components both <20 kW; about 1/3rd were >100 kW
- Marks a shift: Paired applications in the non-residential market have been moving into progressively smaller applications in recent years; no longer the exclusive domain of large users with high demand charges
- The smallest class of non-residential systems typically have PV and batteries of roughly equal size (median kW ratio of 1.2), but with a long upper tail; larger systems typically have batteries sized at about half their respective PV size (median kW ratio of 0.5-0.6)
- As with residential, most non-residential systems have storage durations ranging from 1.5-3 hours, even with a somewhat more diverse product mix

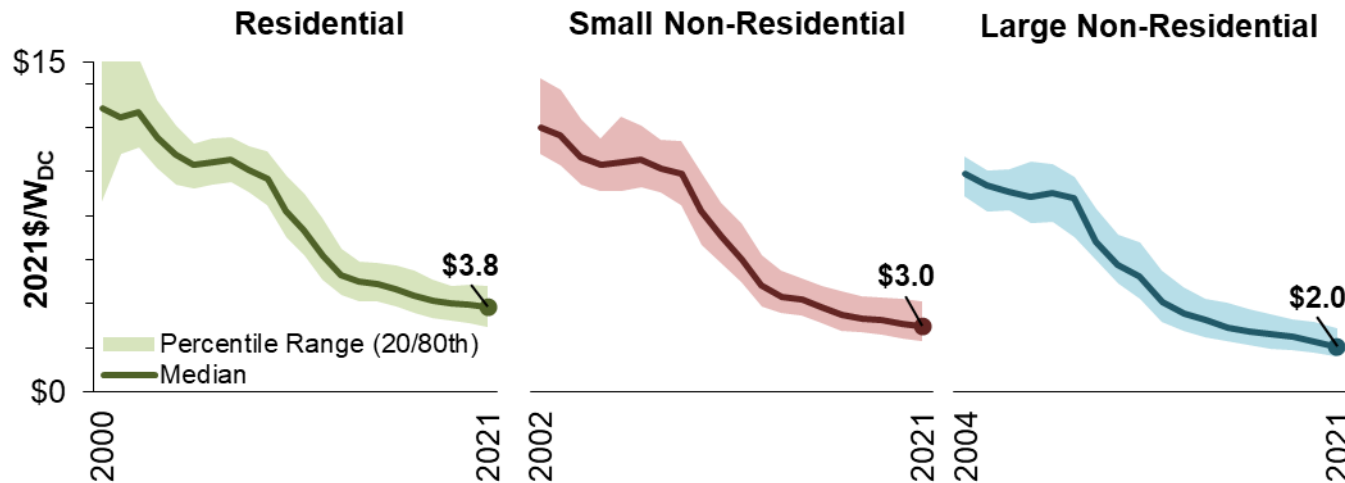
Median Installed Price Trends

A Few Notes on Installed-Price Data

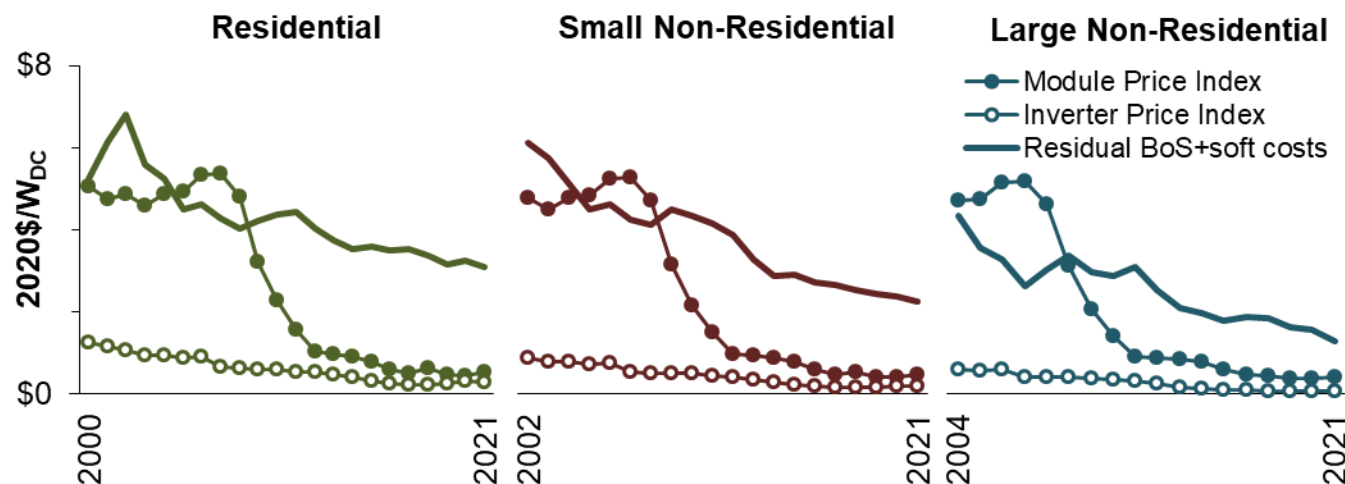
- Unless otherwise noted, results are based on host-owned, stand-alone PV systems (excludes TPO, systems paired with storage)
- Prices may include dealer fees for loan-financed systems
- Data are historical, based primarily on systems installed through the end of 2021, and may not be representative of systems installed more recently or current quotes for prospective projects
- Data are self-reported by PV installers or customers

National Median Prices and Component Costs over Time

National Installed Prices over Time



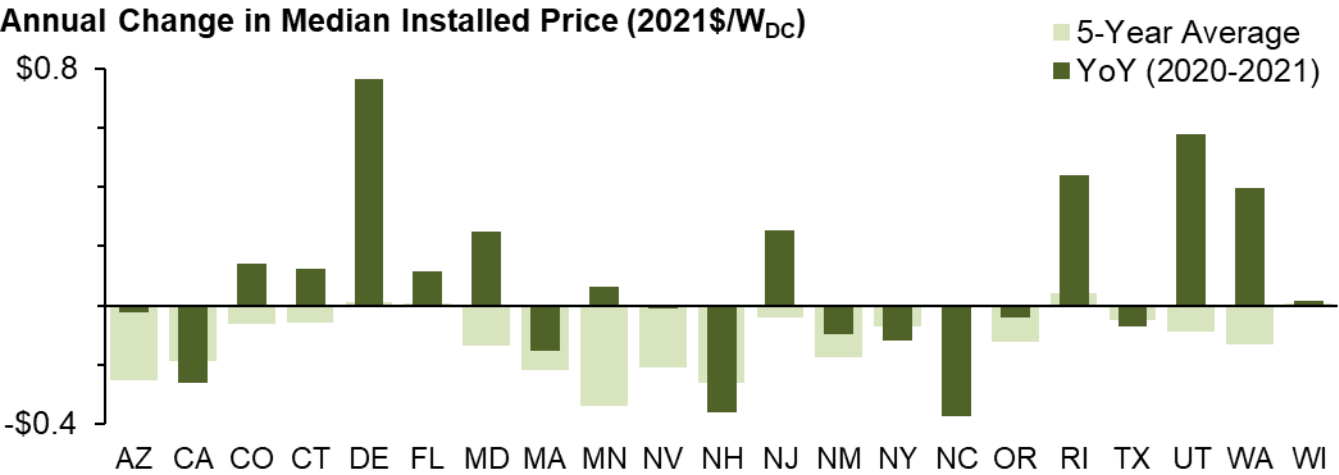
Underlying Trends in Component Costs



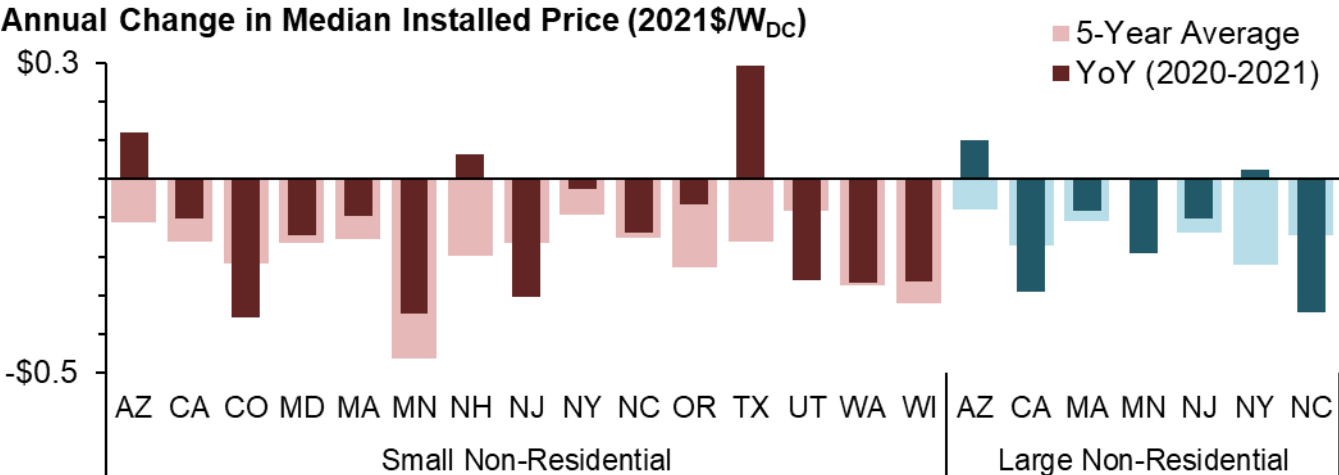
- Over the long-term, median installed prices have fallen by roughly \$0.4/W per year, on average, but price declines have tapered off since 2013, after which price declines averaged \$0.1-0.2/W across segments
- That tapering off is mostly a function of the underlying module-cost trajectory, but also reflects growing customer acquisition costs, loan fees, and other costs embedded in the “Residual BoS+soft costs” (bottom fig)
- Over the long-term, these residual BoS+soft costs have fallen by roughly \$0.1-0.2/W per year, on average
- Over the last year of the analysis period (2020-2021), median U.S. prices fell by \$0.1-0.2/W after adjusting for inflation across the three customer segments, maintaining the same trajectory since 2013
- The YoY price decline occurred despite a slight uptick in module prices in 2021 and supply chain constraints

State-Level Trends in Median Installed Prices

Residential Annual Change in Median Prices



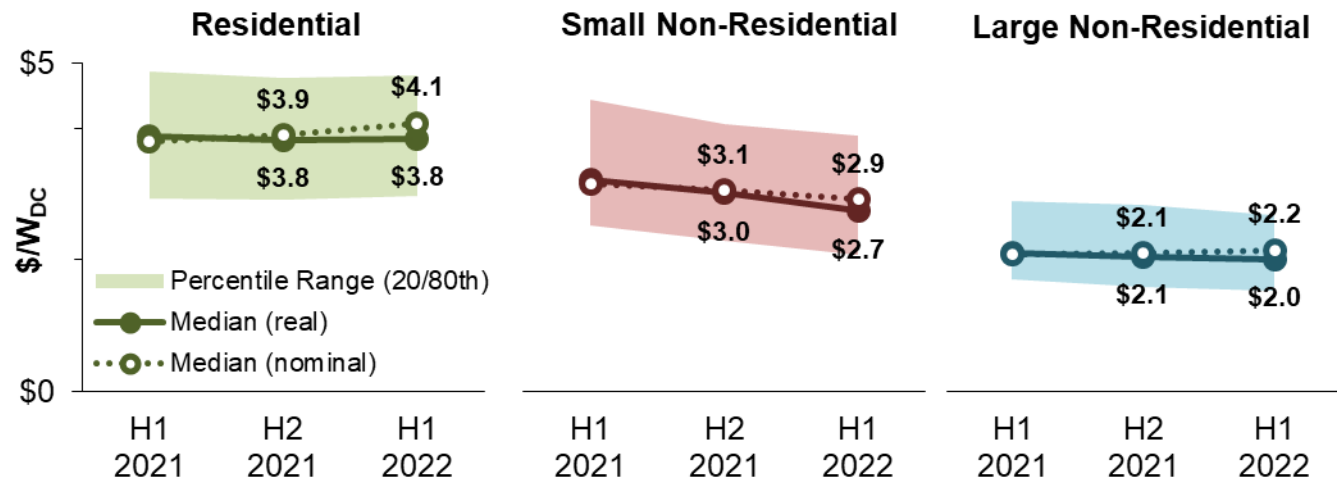
Non-Residential Annual Change in Median Prices



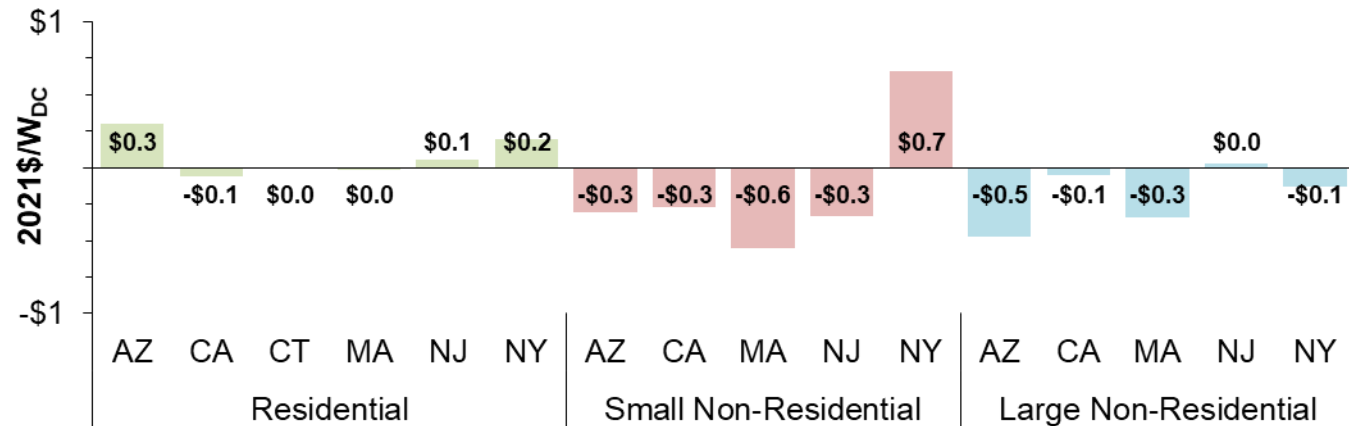
- National trends in median prices are driven heavily by CA, owing to its large share of the sample/market
- Year-over-year (YoY) pricing trends at the state-level can deviate from national trends, but can be fairly volatile (especially for states and sectors with small sample*)
- In the residential sector, median prices increased YoY in more than half of all states, in some cases significantly
- Trends over a 5-year timeframe are more uniform, with most states showing average annual declines of up to \$0.2/W per year
- In the non-residential sector, almost all states saw some YoY decline in median prices; longer lead times can delay the effects of supply-chain constraints
- Over the past 5 years, median non-residential prices have fallen by \$0.1-0.3/W per year in most states

Installed Price Trends for the First Half (H1) of 2022

National Installed Prices (Real and Nominal)



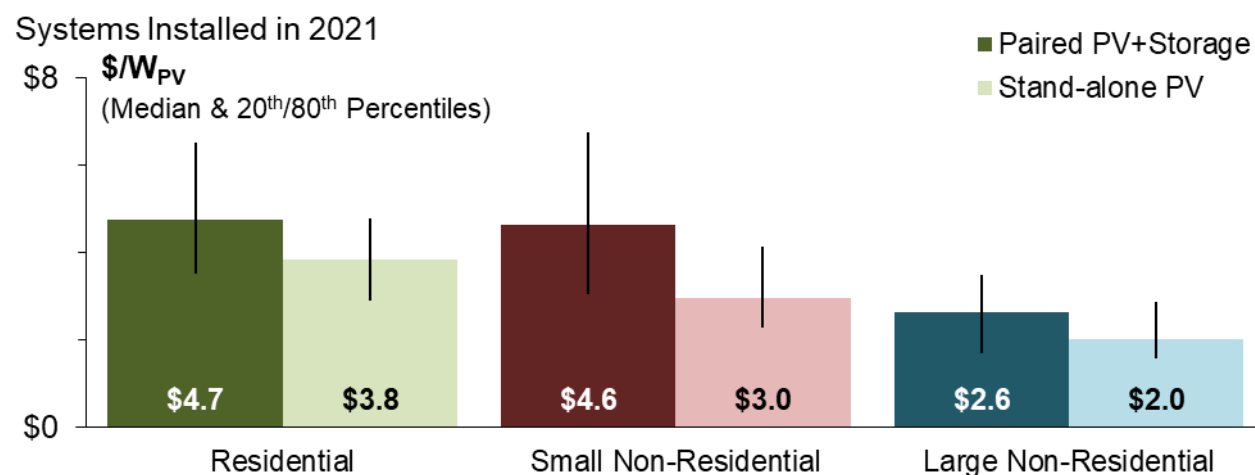
Change in Median Installed Prices: H2-2021 to H1-2022



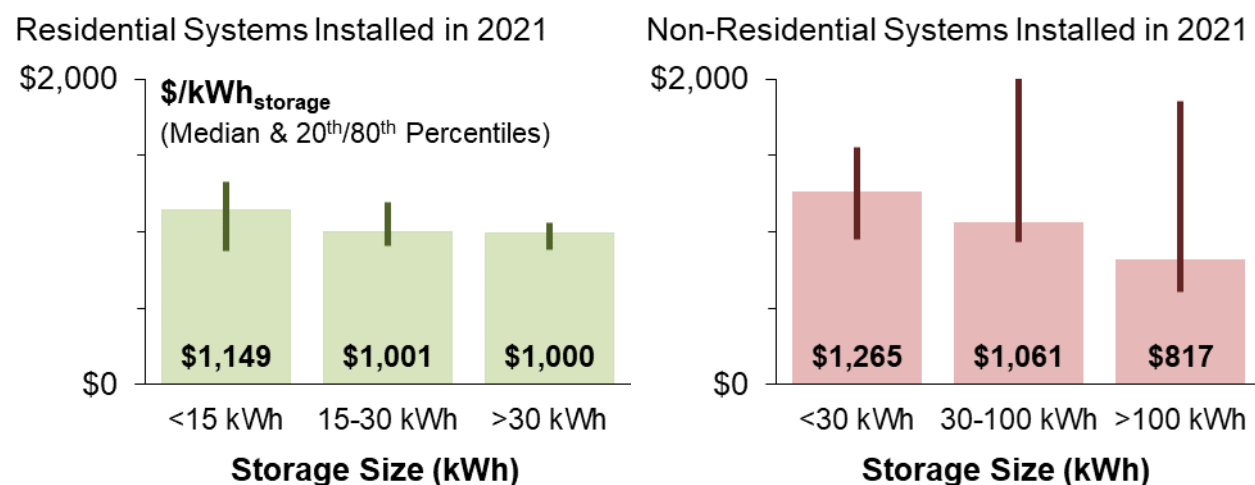
- Figure on the top includes both real and nominal prices
- Nominal prices rose slightly (by \$0.1-0.2/W) for residential and large non-residential systems in H1 2022, but fell by \$0.2/W for small non-residential systems
- In real (inflation-adjusted) dollars, national median prices remained essentially flat for residential systems while falling for both non-residential classes
- Supply chain constraints, widely acknowledged within the industry as putting upward pressure on prices, are partly absorbed within the inflation adjustment
- Among the subset of states in the bottom figure, trends in the residential sector are mixed, with half showing an increase in real prices in H1 2022
- State-level trends in the non-residential sector are more consistent directionally, with almost all showing continued real-price declines in H1 2022

Installed-Price Premium for Paired PV+Storage Systems

Installed Price Comparison: Standalone vs. Paired PV

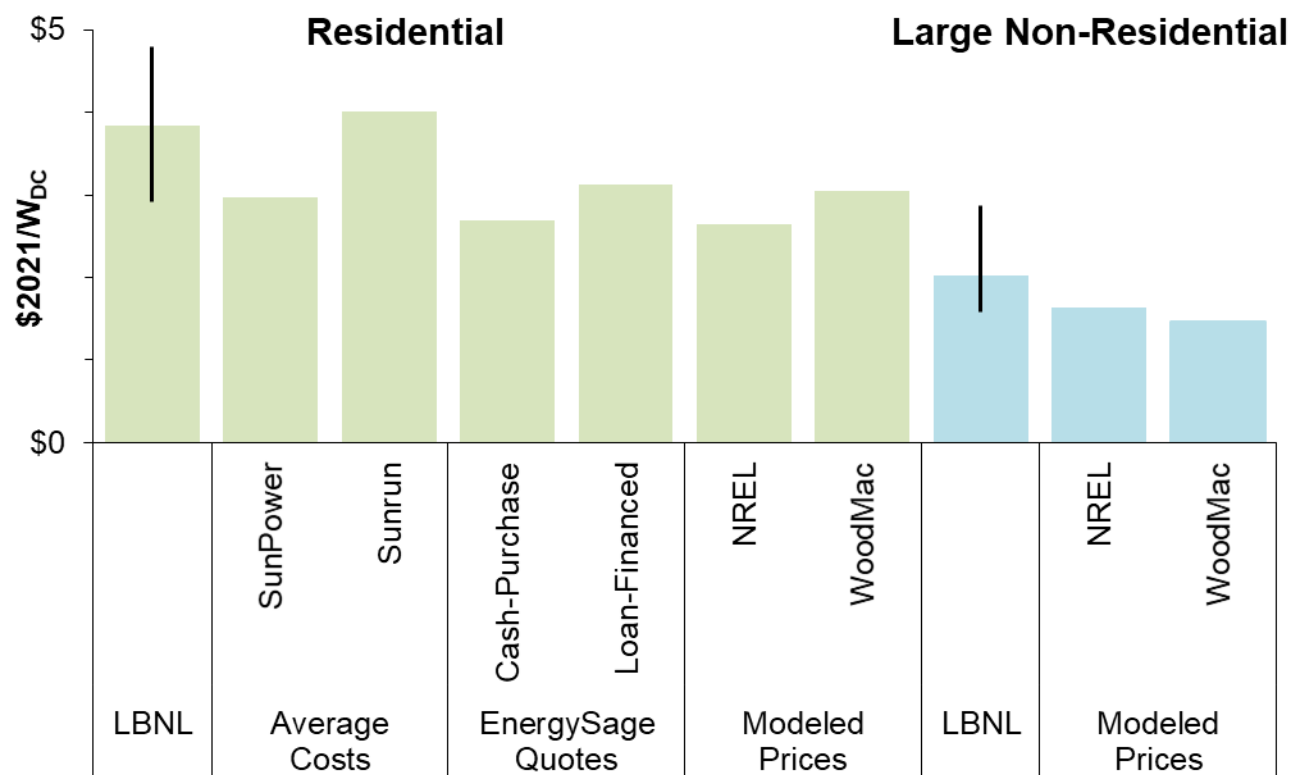


Reported Storage Costs from California's SGIP



- Though otherwise excluded from the trends described in this section, installed prices for paired PV+storage systems are consistently higher than for stand-alone PV
- Direct comparisons can be misleading, given confounding factors; the multi-variate regression analysis (described later) estimates a $\$1.9/W_{PV}$ storage premium for residential PV (for a 5 kW battery with 10-15 kWh of storage capacity)
- Given typical residential PV and storage sizes, this equates to an underlying incremental cost of roughly $\$1200/kWh_{storage}$
- In comparison, median costs for similarly sized residential storage systems funded through California's Self Generation Incentive Program (SGIP) were $\$1,149/kWh$ in 2021
- The SGIP data also point toward modest economies of scale with storage system sizing, especially for large non-residential systems (though the error bands are quite wide)

Comparison of PV Cost and Pricing Benchmarks

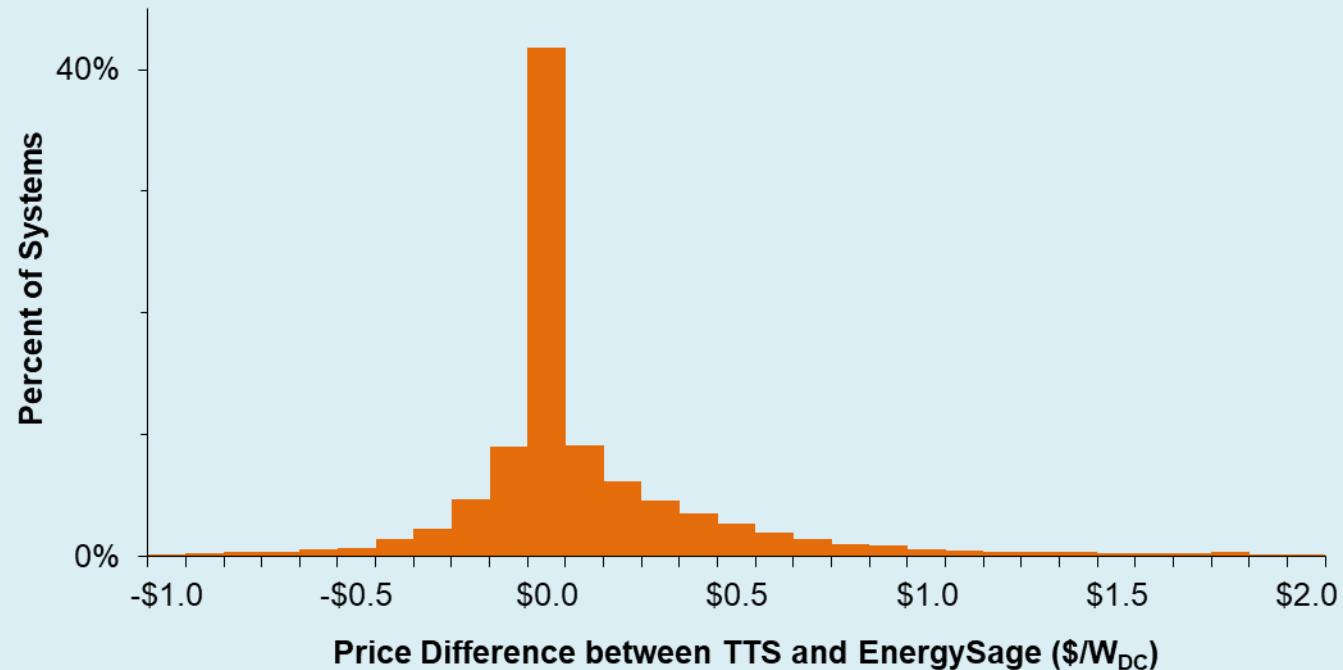


Notes: **LBNL** data are the median and 20th and 80th percentile values among projects installed in 2021. **SunPower and Sunrun** data are based on the companies' quarterly shareholder reports in 2021 (courtesy of D. Feldman, NREL) and are equal to the sum of reported average installation, sales, and general & administrative costs, averaged across the four quarters. **EnergySage** data are the median price quotes issued in 2021, for cash-purchase standalone PV systems, as calculated by Berkeley Lab from data provided by EnergySage. **NREL** data represent modeled turnkey costs in Q1 2021 for a 7.2 kW residential system and a 500 kW ground-mounted commercial system (Ramasamy et al. 2021). **WoodMac** data are from the Solar Market Insight 2021 Year-in-Review, and are based on modeled turnkey prices, averaged across quarters.

- A variety of other PV cost and pricing benchmarks exist, based on differing methods and data sources, and serving different purposes
- On the residential side, national median installed prices from Tracking the Sun (TTS) are similar to average costs reported by SunRun, but other benchmarks align more closely with the 20th percentile values
- On the non-residential side, fewer benchmarks are available and are limited to large systems, both of which align more closely with 20th percentile levels from TTS
- In general, divergence across benchmarks can reflect differences in factors such as price vs. cost, mark-ups, system design, installer characteristics, scope of costs included, and other factors
- Dealer fees for loan-financed systems likely add 10-25% to the reported price for some subset of TTS systems

Comparison to Matched EnergySage Quotes

Comparison of Prices using either ES Cash or Loan Price, whichever is closer to TTS
Stand-alone residential PV systems (all years)



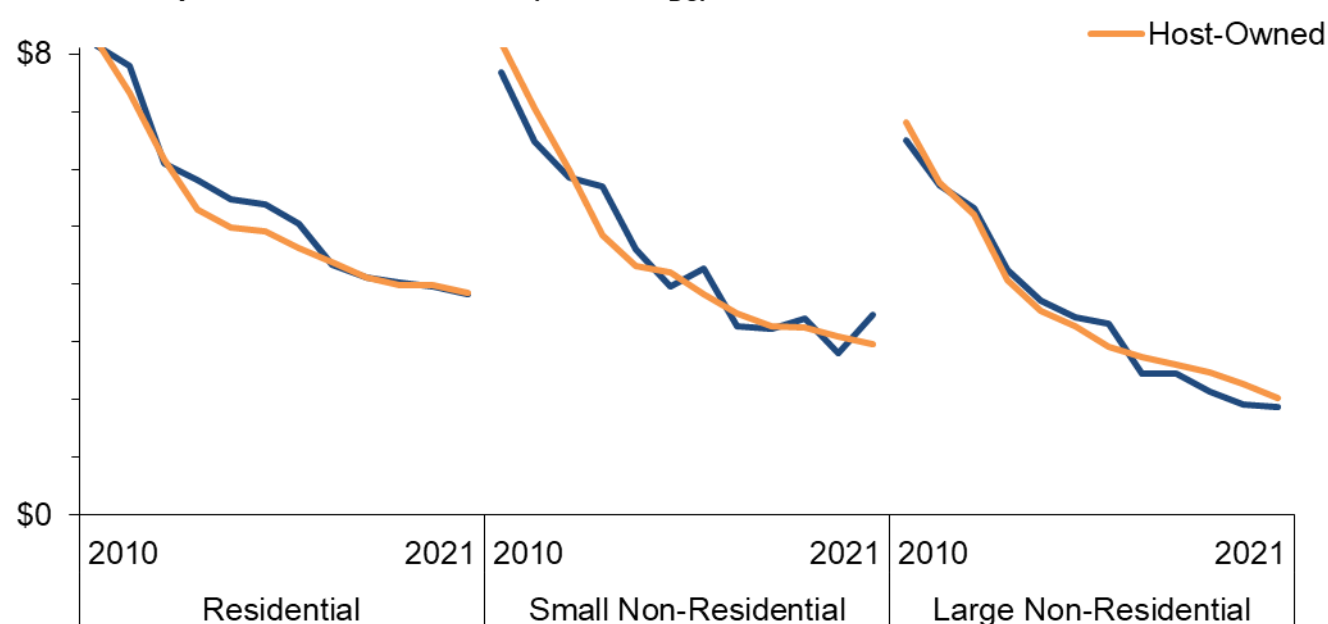
- As the previous slide shows, price quotes issued over EnergySage are generally lower than the national median installed price from Tracking the Sun
- For a subset of EnergySage price quotes culminating in an installed system, we can identify the corresponding record from the Tracking the Sun dataset, and compare prices between the two data sources
- The distribution indicates generally close agreement (a median of \$0.0/W), confirming that the differences shown previously are not driven by underlying data reporting discrepancies—but, more likely, are due to the effects of quote platforms on price competition
- Where differences do exist among this matched set, they are generally small (two-thirds are within -0.2 to +0.2/W), and can go in either direction, though they do skew to the right

Installed Prices Reported for TPO Systems

- Depending on the particular project or firm, installed prices reported for TPO systems may represent:
 - An appraised value or fair-market value construct (as often used as the basis for federal tax credits)
 - An actual transaction price between the third-party financier and an independent installer, which may or may not reflect all soft costs
- As a precautionary step, pricing data reported for TPO systems are excluded from the installed-price analysis, on the grounds that they cannot be meaningfully compared to prices reported for host-owned systems
- Nevertheless, the data show that prices for TPO systems generally correspond quite closely to those for host-owned systems

Installed Prices for TPO vs. Host-Owned Systems

Median Reported Installed Prices (2021\$/W_{DC})

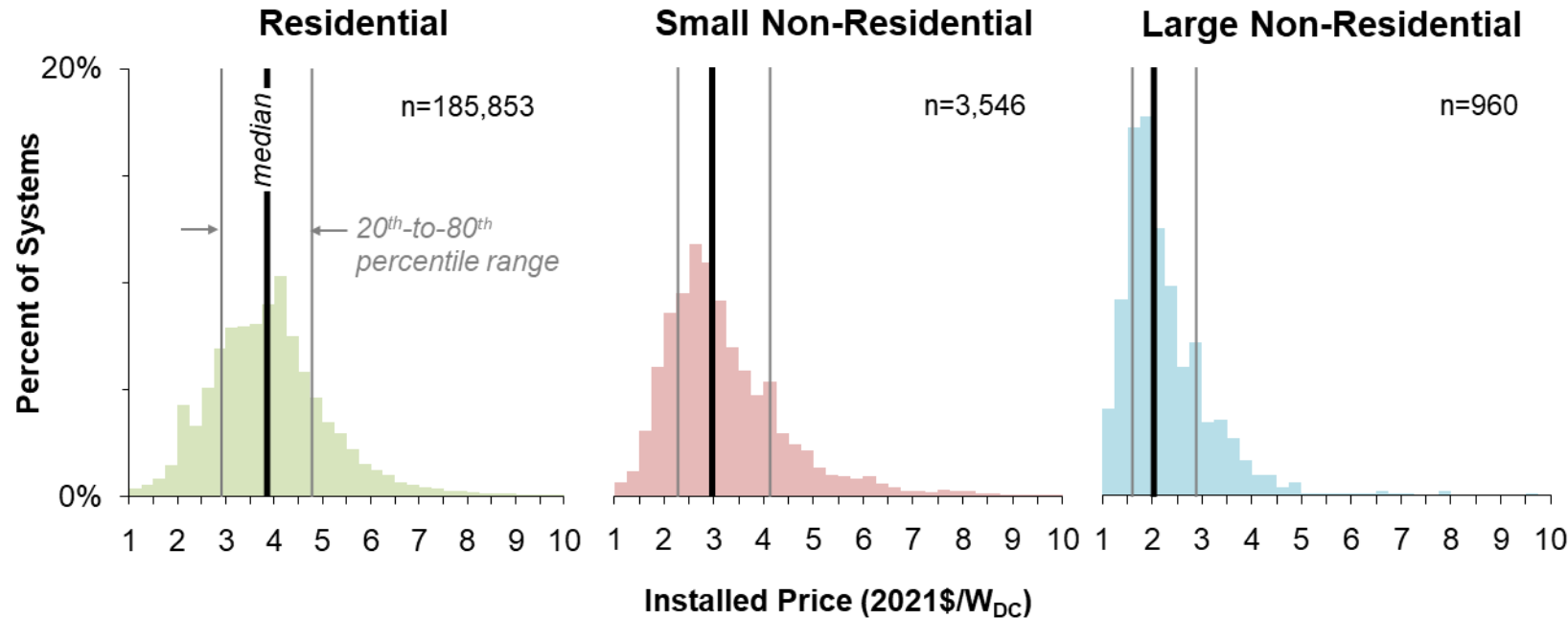


Note: TPO systems not otherwise included in installed-price analysis; figure above for reference only

Variability in Installed Prices

Installed-Price Variation Across Systems

Installed-Price Distribution for Stand-Alone PV Systems Installed in 2021



20th to 80th Percentile Bands for Systems Installed in 2021

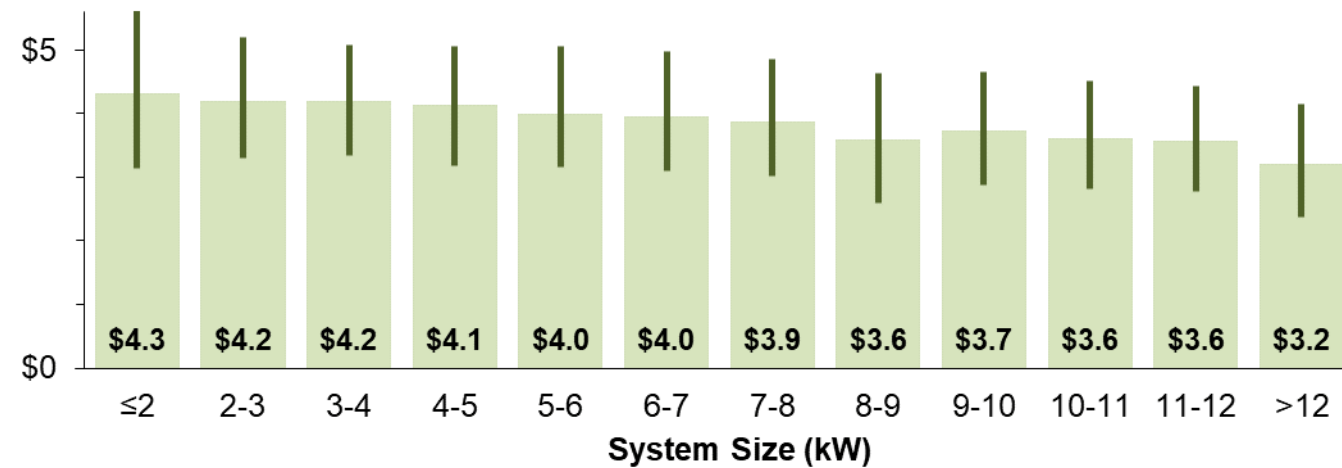
- \$2.9/W - \$4.8/W (residential)
- \$2.3/W - \$4.1/W (small non-residential)
- \$1.6/W - \$2.9/W (large non-residential)

- Wide pricing variability persists within each customer segment
- Reflects underlying differences in:
 - Project characteristics
 - Installer attributes
 - Local market, policy, and regulatory environment
- We explore a subset of pricing drivers in the following slides, through a combination of **descriptive analysis** and a multi-variate **regression model**
 - A variety of other studies have also investigated pricing drivers, often leveraging TTS data

Economies of Scale with PV System Size

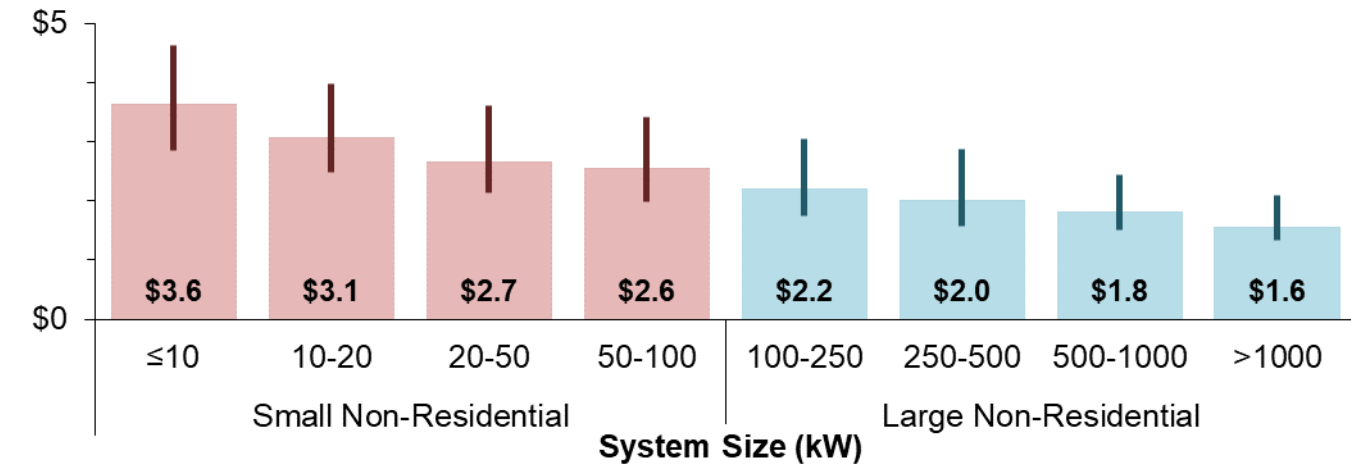
Residential Systems Installed in 2021

Median Installed Price and 20th/80th Percentiles (2021\$/W_{DC})



Non-Residential Systems Installed in 2021

Median Installed Price and 20th/80th Percentiles (2021\$/W_{DC})

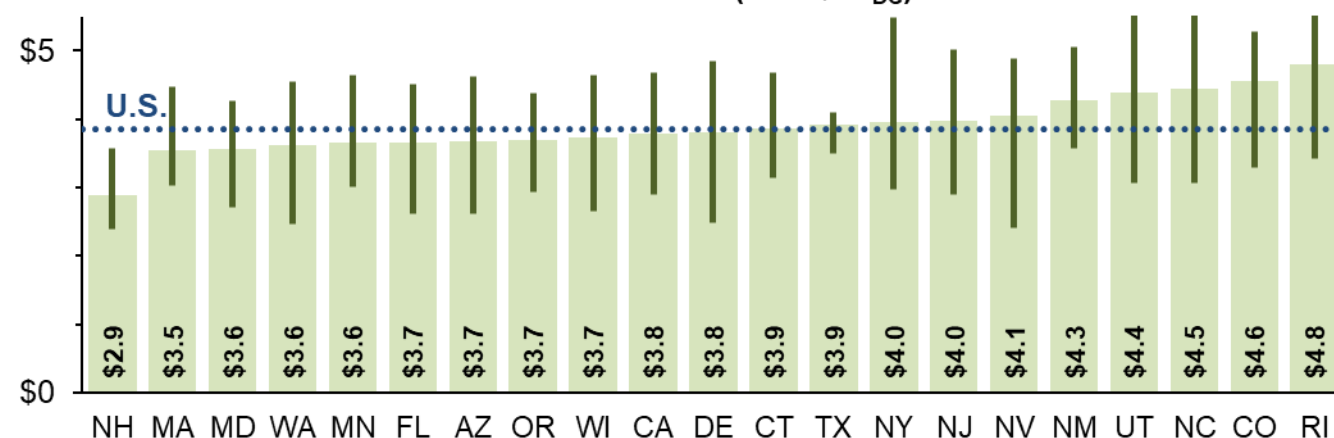


- Economies of scale arise because of the many fixed costs (e.g., permitting, customer acquisition, financing, etc.)
- Among residential systems installed in 2021, median prices were \$1.1/W lower for the largest residential systems compared to the smallest
- This price differential coincides exactly with what the later regression model implies for the same size range
- Among non-residential systems, which span an even wider size range, median prices were \$2.0/W lower for systems >1,000 kW, compared to the smallest non-residential systems ≤10 kW

State-Level Differences in Installed Prices

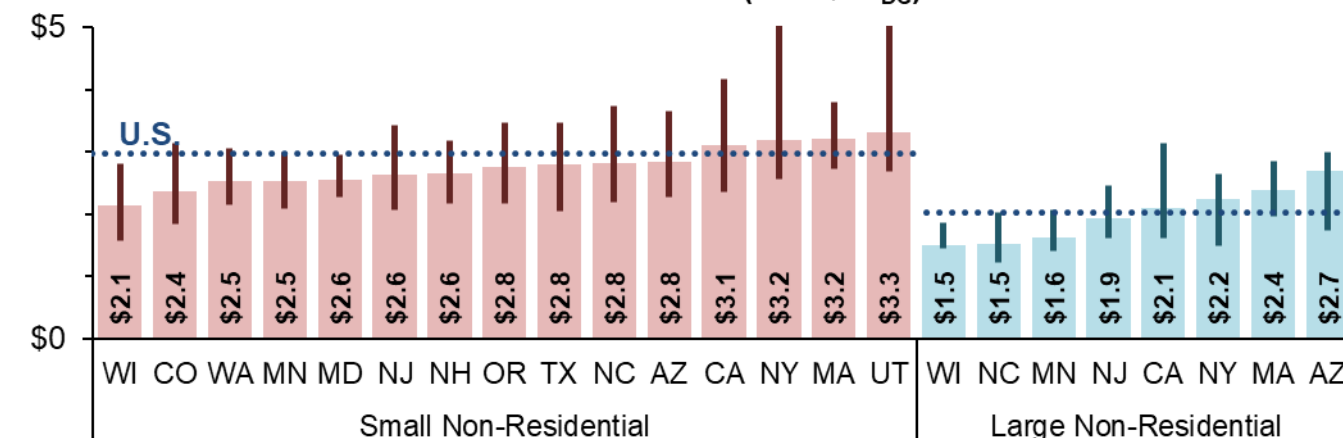
Residential Systems Installed in 2021

Median Installed Price and 20th/80th Percentiles (2021\$/W_{DC})



Non-Residential Systems Installed in 2021

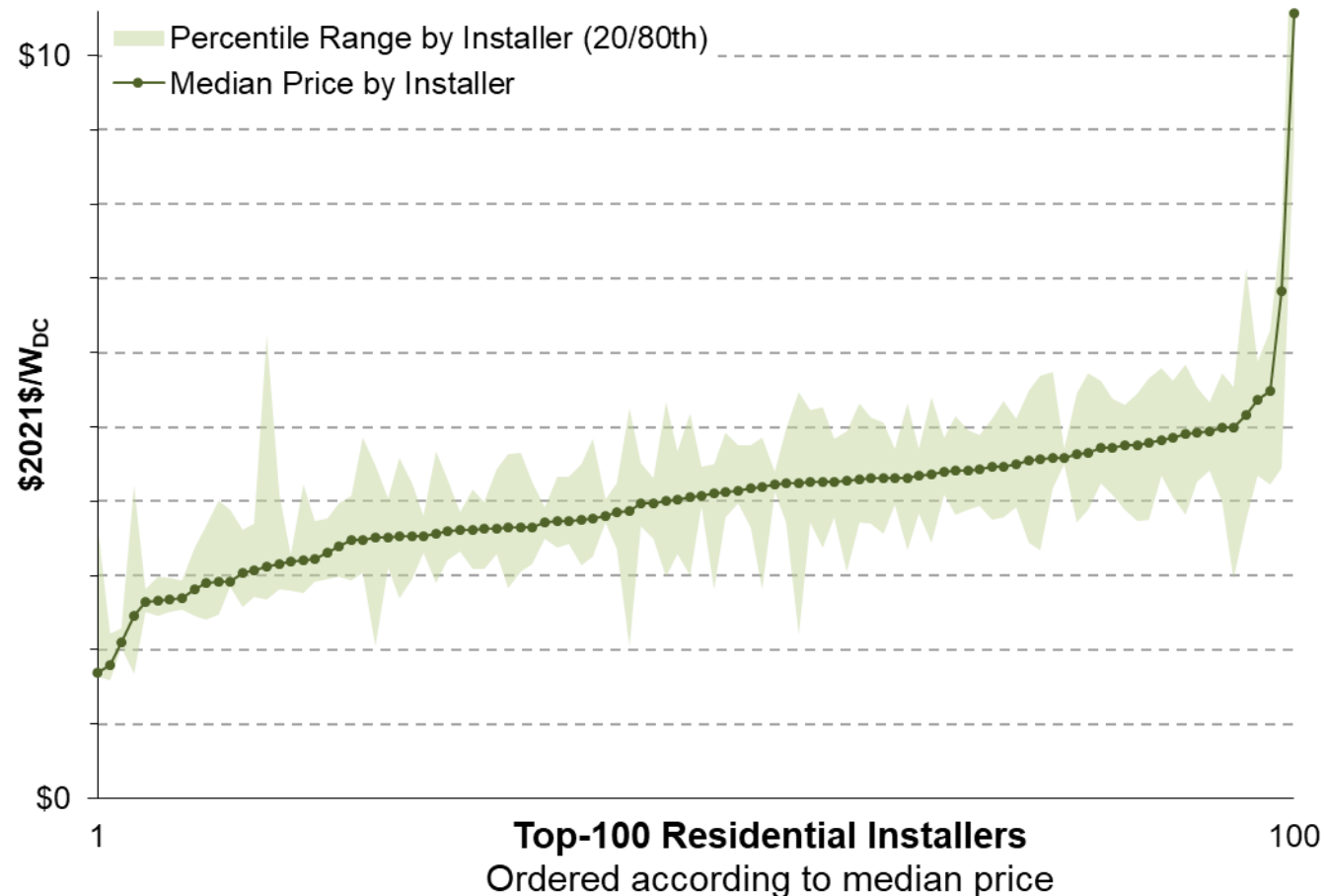
Median Installed Price and 20th/80th Percentiles (2021\$/W_{DC})



- Median prices vary substantially across states within each of the customer segments
- Differences are especially pronounced in the residential sector, where median prices varied by almost \$2/W across the 21 states shown (driven by particularly low prices in NH)
- Cross-state pricing differences can reflect idiosyncratic features of particular states (e.g., a single large installer with anomalous prices) as well as more-fundamental differences in market and policy conditions
- The later regression analysis controls for some of those differences (e.g., market size, installer concentration, population density, income levels), though still shows substantial cross-state differences

Installer-Level Pricing Differences

Top-100 Host-Owned Residential Installers in 2021



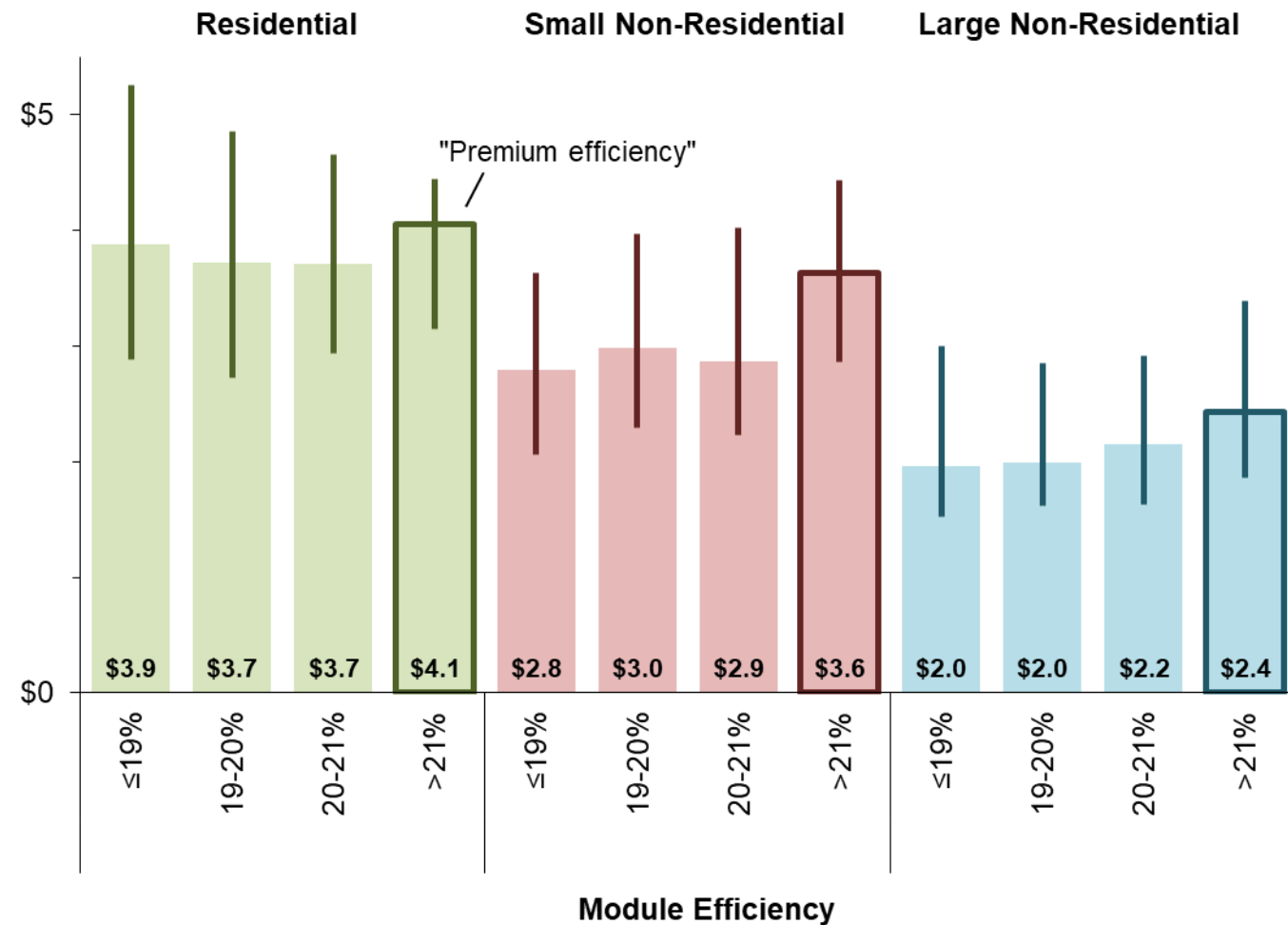
Notes: Each dot represents the median installed price of an individual installer, ranked from lowest to highest, while the shaded band shows the 20th to 80th percentile range for that installer.

- Ignoring the tails, median prices across the top-100 residential installers in 2021 ranged from \$2.5/W to \$5.0/W, with more than half registering median prices above \$4.0/W
- Firm-level experience is one potential reason for pricing differences across installers; the later regression analysis implies roughly a \$0.14/W range in prices between firms at the 20th and 80th percentile levels of experience
- Other firm-level characteristics may also contribute to the variation shown here (e.g., equipment preferences and relationships, business models, loan partners), as well differences in how each installer reports prices
- In addition, some apparent firm-level pricing differences may also just reflect features of the local markets in which different firms operate

Installed-Price Differences by Module Efficiency

Installed Prices by Module Efficiency for 2021 Systems

Median Installed Price and 20th/80th Percentiles (2021\$/W_{DC})

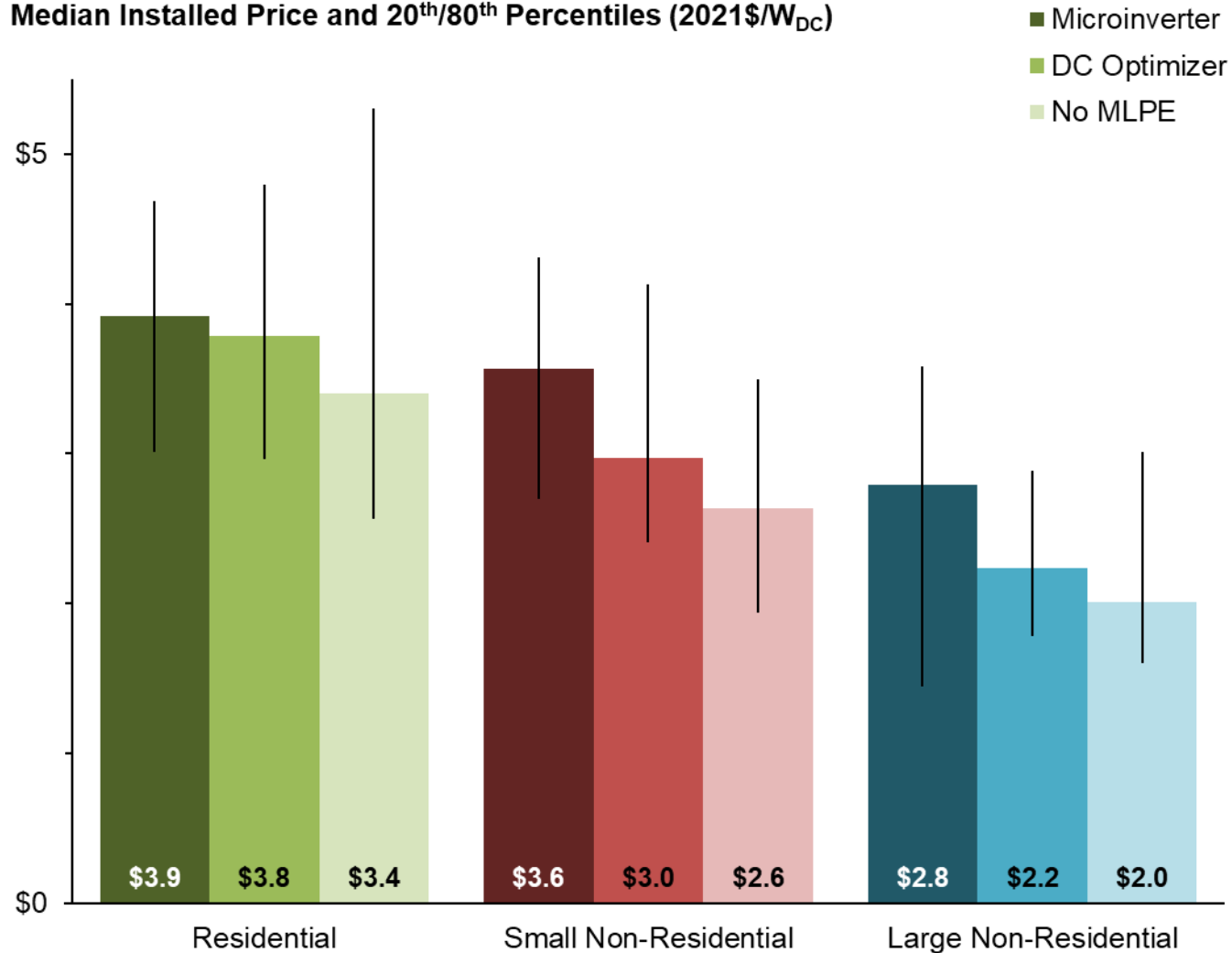


- Higher efficiency modules can sell at a premium, but may allow for savings on BoS costs, potentially offsetting the higher module price
- The trends are somewhat irregular, but in general, systems with the “premium efficiency” (>21%) modules tend to have higher prices
- These descriptive trends are consistent with the regression model, which shows that residential systems with module efficiencies >21% cost roughly \$0.1/W more, on average, after controlling for other factors

Installed-Price Differences by Inverter Technology

Installed Prices for 2021 Systems with and without MLPEs

Median Installed Price and 20th/80th Percentiles (2021\$/W_{DC})

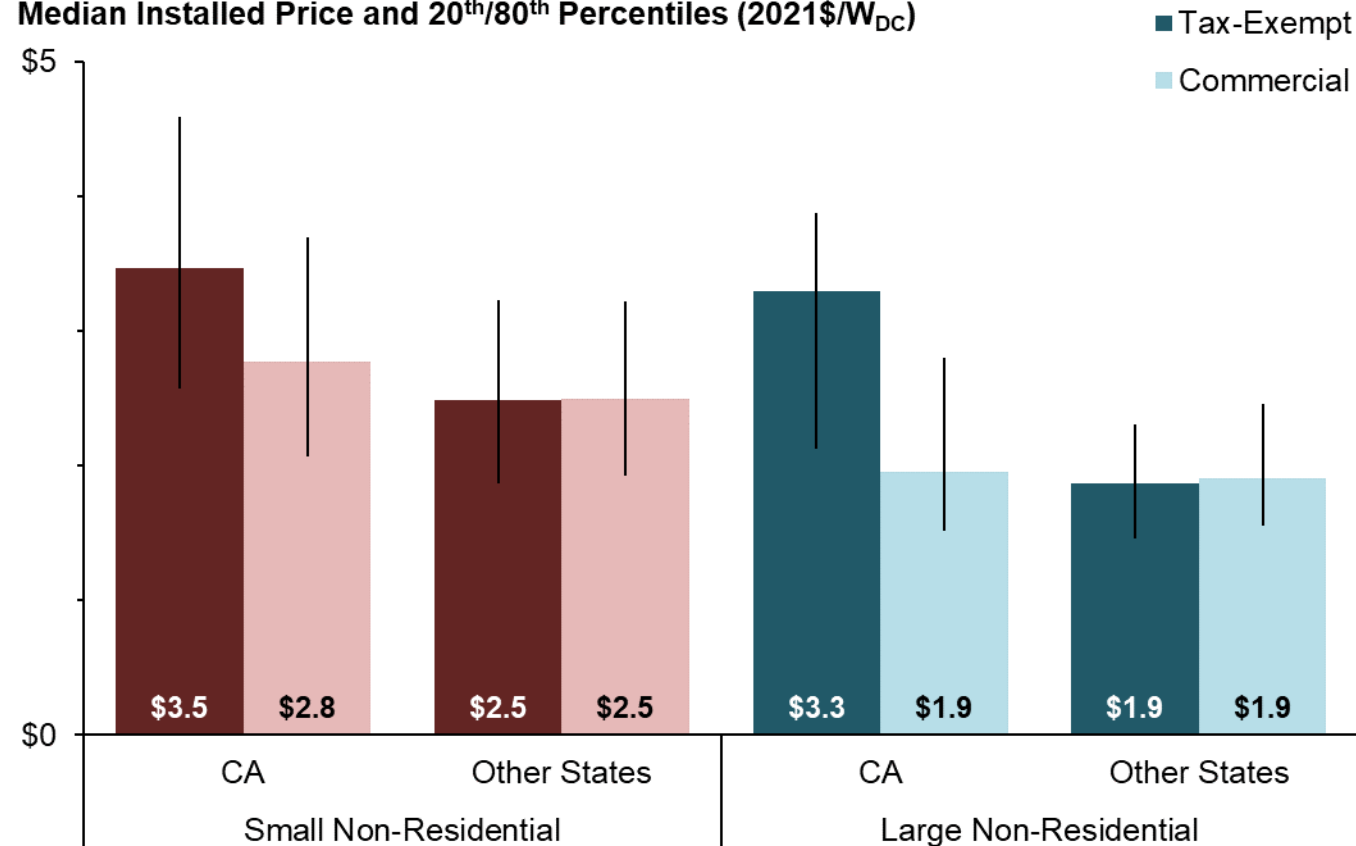


- Installed-price differences by inverter technology type show a consistent pattern across all three customer segments, with the highest price for systems with microinverters, lower for those with DC optimizers, and lowest for those without any MLPEs
- For example, among residential systems, median prices are \$0.5/W higher for systems with microinverters and \$0.4/W higher for systems with DC optimizers, compared to those with neither
- Regression analysis (presented in the next section) shows similar values, though the implied premium is slightly higher for residential systems with DC optimizers than for those with microinverters (\$0.4/W)

Installed-Price Differences by Non-Residential Customer Type

Tax-Exempt vs. Commercial Non-Res. Systems in 2021

Median Installed Price and 20th/80th Percentiles (2021\$/W_{DC})



Notes: Summary statistics are based on a somewhat narrow subset of data providers who provide customer segmentation details for non-residential systems.

- In California, installed prices are higher for tax-exempt site hosts (schools, government, non-profits), compared to prices for commercial site hosts
- Differences are especially pronounced among large non-residential systems
- But no apparent difference exists across these customer types in other states (though for many states, detailed data on business type are unavailable)
- In general, higher prices for systems at tax-exempt customer sites could reflect a number of possible characteristics of tax-exempt customers, for example:
 - requirements for domestically manufactured components or prevailing wage/union labor
 - prevalence of shade or parking structures
 - lower borrowing costs

Multi-Variate Regression Analysis of Residential Installed Prices

Econometric Model Overview and Results

- Multi-variate linear-regression model used to explain variation in **residential** installed prices in 2021
$$p = \alpha + system\beta_1 + market\beta_2 + installer\beta_3 + S + Q + \varepsilon_i$$
- Dependent variable (p) is installed price (in \$/W); independent variables include system, market, and installer-level factors, as well as state (S) and quarterly (Q) fixed-effects; many of the system-related variables are binary
- Complements the descriptive analysis by showing the effects of individual pricing drivers while controlling for other confounding factors
- The coefficients in the table represent the average change in PV installed price (\$/W) given a unit change in each of the variables listed (or, for binary variables, if that variable is true)
- Many of these individual results are referenced earlier in the descriptive analysis; others are discussed on the next slide

Variable		Coefficient
System	System size (kW)	-0.19*
	System size squared	0.01*
	Premium module (binary)	0.11*
	Microinverter (binary)	0.47
	DC optimizer (binary)	0.52*
	New construction (binary)	-0.38*
	Ground-mounting (binary)	0.38*
Market	Battery storage (binary)	1.89*
	HHI (market concentration)	-0.02
	HHI squared	-0.43
	Market size (x1,000)	-0.03*
	Population density (x1,000)	0.05*
Installer experience (x1,000)		0.00*
N		-0.01*
R ²		158,651
		0.16

* p<0.05

Additional Insights from Residential Regression Results

- **New Construction:** The model suggests that prices are \$0.4/W lower for systems installed during new home construction, consistent with previous research.^a
- **Ground-Mounting:** Though relatively uncommon in the residential sector, the model indicates that ground-mounting adds about \$0.4/W to the installed price.
- **Market structure:** The coefficients are not statistically significant, but are negative, suggesting that prices are generally lower in more-concentrated markets. Other studies have shown that this may be true up to a point, but that prices are generally higher in very concentrated markets.^b
- **Market size:** The negative coefficient on market size suggests that prices are generally lower in markets with more cumulative PV installations.
- **Population Density:** The positive coefficient on population density suggests that prices are generally higher in more densely-populated areas (e.g., in cities rather than rural areas).
- **Median Zip-Code Income:** The coefficient on median income is zero, suggesting that prices are independent of income levels. Note that previous studies have found different results.^c

Additional Resources

For further reading on analyses of PV prices related to these findings, see: a) “Solar Economies of Scope through the Intersection of Four Industries.” 2018. NREL. b) “Non-monotonic effects of market concentration on prices for residential solar photovoltaics in the United States.” 2020. Energy Economics; c) “Deconstructing Solar Photovoltaic Pricing.” 2016. The Energy Journal.

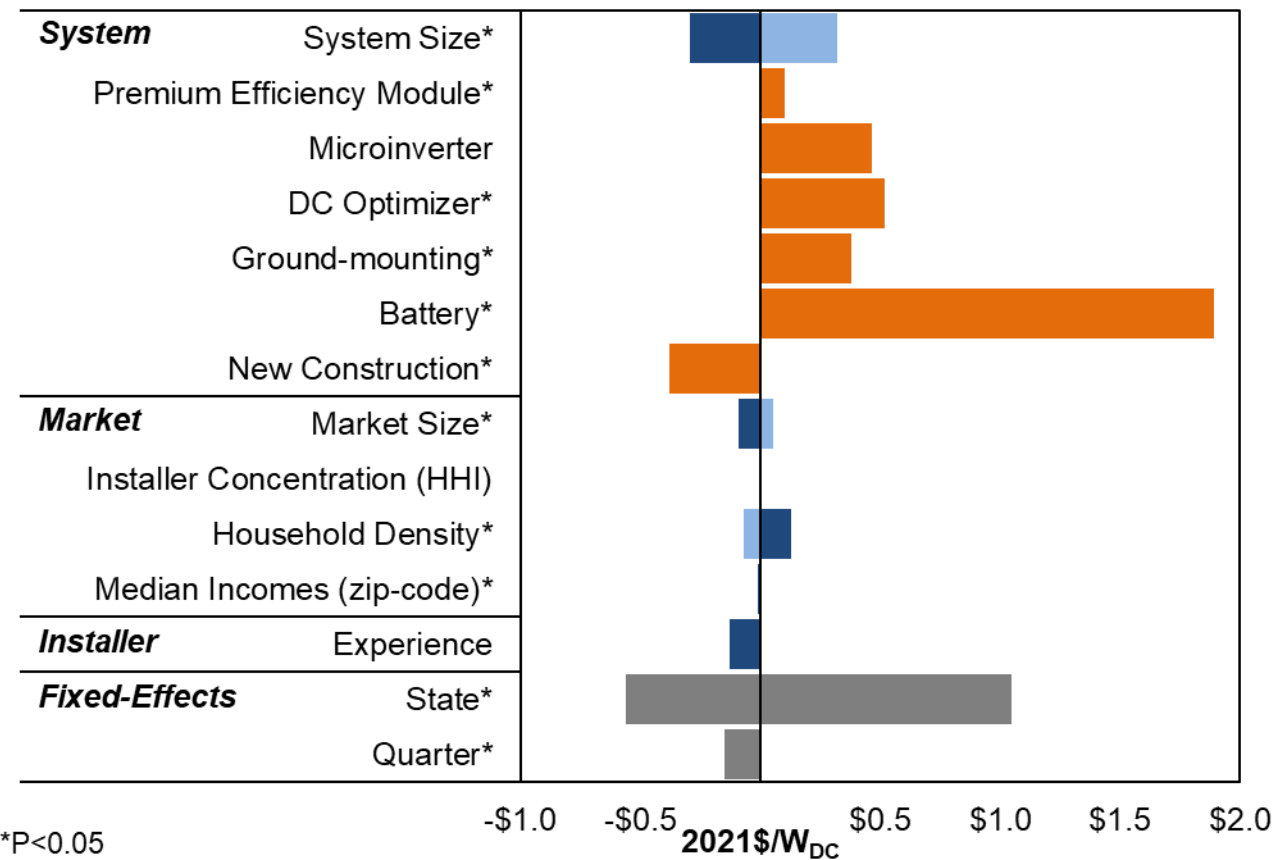
Sensitivity of Installed Prices to Modeled Drivers

This figure provides a sense of scale for the relative contribution of each pricing driver to overall pricing variability

- Of the system-level pricing drivers, battery storage has by far the biggest effect (\$1.9/W), though microinverters, DC-optimizers, ground-mounting, and new construction all have relatively large effects (\$0.4-0.5/W) as well
- Effects associated with the various market- and installer-related drivers are all relatively small (less than \$0.2/W), but in general are directionally intuitive
- Of particular note is the wide range across the state fixed-effects variables (\$1.6/W), suggesting the presence of strong state-level pricing drivers beyond those explicitly captured in the model (e.g., cost-of-living, retail rates, incentives, solar insolation, permitting processes)

Effect on Installed Prices

- Continuous variable: Price change from median to 80th percentile of variable value
- Continuous variable: Price change from median to 20th percentile of variable value
- Binary variable: Price change if True
- Fixed effects variable: Price range from min to max

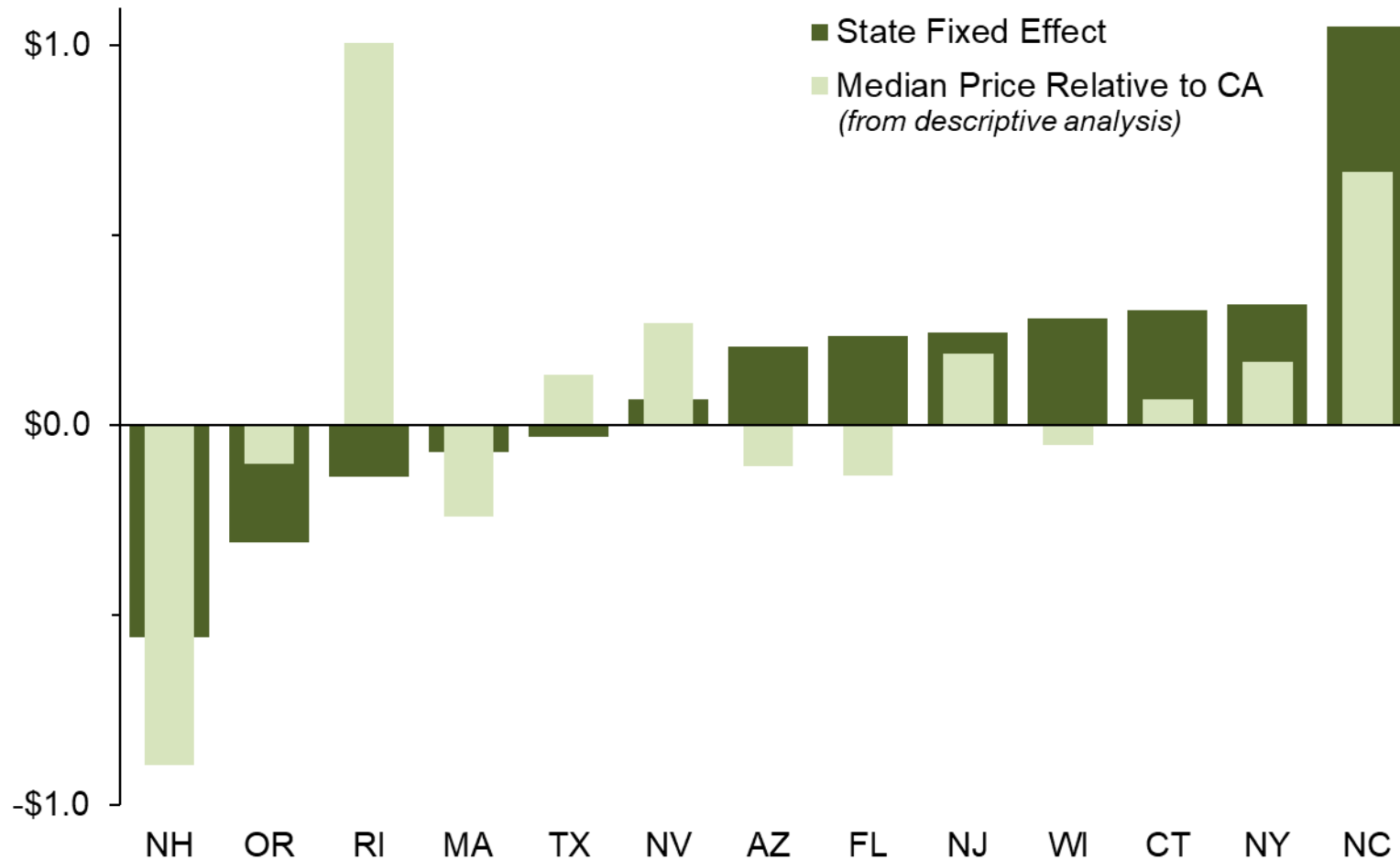


State Fixed-Effects

Residual Pricing Differences After Controlling for Other Factors

State Fixed Effects Compared to Difference in Median Prices

Pricing Difference Relative to California (2021\$/W_{DC})



- State fixed effects represent the difference in average residential price, relative to California, after controlling for other variables
- Fixed effects may be larger or smaller than the simple difference in state median prices, and may even point in different directions
- RI is a dramatic case, where the fixed effects are far smaller than the difference in medians, indicating that much of the apparent price difference is related to modeled variables
- Across most of the states shown, fixed effects vary within a band of roughly $\pm \$0.3/W$, which reflects additional unexplained differences across states (e.g., due to unobserved variables and/or idiosyncrasies of the data)

For more information

Download the report, data, and other related materials:

<http://trackingthesun.lbl.gov>

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Appendix

List of Entities Contributing Data

AR State Energy Office	FL Energy & Climate Commission	PA Department of Environmental Protection
AZ Ajo Improvement Company	FL Gainesville Regional Utilities*	PA Sustainable Development Fund
AZ Arizona Public Service*	FL Orlando Utilities Commission*	RI National Grid*
AZ Duncan Valley Electric Cooperative	HI County of Honolulu (via Ohm Analytics)*	RI Commerce Corporation*
AZ Mohave Electric Cooperative	IL Dept. of Commerce & Economic Opportunity	TX Austin Energy*
AZ Morenci Water and Electric	IL Power Agency*	TX CenterPoint*
AZ Navopache Electric Cooperative	MA DOER*	TX CPS Energy*
AZ Salt River Project*	MA Clean Energy Center*	TX Frontier Associates*
AZ Sulfur Springs Valley Electric Cooperative	MD Energy Administration*	TX Oncor*
AZ Trico Electric Cooperative	ME Efficiency Maine	UT Office of Energy Development*
AZ Tucson Electric Power*	MN Department of Commerce	VA Dept. of Mines, Minerals and Energy
AZ UniSource Energy Services*	MN Xcel Energy/Northern States Power*	VT Energy Action Network
CA Center for Sustainable Energy (Bear Valley Electric)	NC Sustainable Energy Association*	VT Energy Investment Corporation
CA Center for Sustainable Energy (PacifiCorp)	NH Public Utilities Commission*	WA Puget Sound Energy*
CA City of Palo Alto Utilities	NJ Board of Public Utilities*	WA Washington State University
CA Energy Commission*	NM Energy, Minerals & Natural Resources Dept.*	WI Focus on Energy*
CA Imperial Irrigation District	NM Public Service Company of New Mexico*	
CA Los Angeles Department of Water & Power	NM Xcel Energy*	
CA Public Utilities Commission*	NV NV Energy*	
CA Sacramento Municipal Utility District*	NY State Energy Research and Development Authority*	
CO Xcel Energy/Public Service Company of Colorado*	OH Public Utilities Commission*	
CT Green Bank*	OR Energy Trust of Oregon*	
CT Public Utilities Regulatory Authority*	OR Department of Energy*	
DC Public Service Commission*	OR PacifiCorp	
DE Dept. of Natural Resources and Env. Control*	PA Dept. of Community and Economic Development	

**denotes active data providers*